**Setting Up a Remote Accessing of a PV Plant and Its Analysis**

By

Wong Hoong Wei

15860

**Dissertation submitted in partial fulfillment**

**of the requirement for the**

**Bachelor of Engineering (Hons)**

**(Mechanical Engineering)**

**JANUARY 2016**

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

___________________
WONG HOONG WEI

# CERTIFICATION OF APPROVAL

**Setting Up a Remote Accessing of a PV Plant and Its Analysis**

By

Wong Hoong Wei

15860

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

_______________________________
SYED IHTSHAM UL-HAQ GILANI

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January,2016

# ABSTRACT

The growing interest and increasing installation capacity of photovoltaic (PV) power plants have raised the awareness of the necessity and importance of better managing the PV power plant system in order to harvest the optimal energy yield from PV power plant. To accomplish above objectives, sufficient supervision and monitoring the health and performance of the PV system are necessary. In comparison to huge PV power plant, which can afford to have complicated PV monitoring systems and dedicated personnel available on site for continuous monitoring and maintenance, small-scale PV plants installed for residential or commercial and remote area usage are often insufficiently monitored after installation.

This research presented a remote PV plant in UTP to be monitored remotely. The performance parameters of the plant is evaluated from the monitored data. It is observed that the yields and consequently the performance ratio of the plants depend strongly on the energy demand as well as on the state of charge of the battery. This is a consequence of the method used to control the energy flow in the local grid. The performance ratio of the plant varied between 12.90% and 29.74%. The low PR value of the system is mainly due to the system losses.

# ACKNOWLEDGEMENT

First, I would like to convey my sincere gratitude to my Final Year Project main advisor, Assoc. Prof. Dr. Syed Ihtsham Ul-Haq Gilani and my co-supervisor, Prof Dr. Hussain Al-Kayiem. They have been supportive of my project. Their kind guidance and advice have assisted me to finish my project in the duration allocated by the university. This project would not be possible if without their continuous support. Assoc. Prof. Dr Syed Ihtsham Ul-Haq Gilani has always been patient guiding me to finish my project and my dissertation. He always encourages and motivate me to expand my knowledge further and to step outside of my comfort zone. He always examine my work patiently and guide me to correct my mistakes.

Besides, I would like to thank the Department of Mechanical Engineering of Universiti Teknologi PETRONAS for their kind effort for approving this project to be conducted. This excellent opportunity has not only enhance my knowledge but also both my technical and soft skills. Thanks to their enthusiasm and passion in preparing a great academic structure, I am able to be involved in such an interesting and beneficial project.

# CONTENTS

## LIST OF FIGURE

## LIST OF TABLE

# ABBREVIATION & NOMENCLATURE

| | |
|---|---|
| A | Ampere |
| AC | Alternating current |
| DC | Direct current |
| $E_A$ | Array energy output |
| $E_{pv}$ | Actual energy amount to the load |
| $G_i$ | Solar Irradiance |
| $I_{mp}$ | Optimum operating current |
| $I_{sc}$ | Short Circuit Current |
| kWp | Kilowatt peak power |
| $L_c$ | Array Capture Loss |
| $L_s$ | System losses |
| MW | Megawatt power |
| MPP | Maximum power point |
| $\eta_{STC}$ | Nominal efficiency of the PV module |
| PV | Photovoltaic |
| $P_{max}$ | Nominal maximum power |
| PR | Performance Ratio |
| $P_0$ | PV array peak power |
| $V_{mp}$ | Optimum operating voltage |
| $V_{oc}$ | Open circuit voltage |
| $Y_A$ | Array Yield |
| $Y_F$ | Final Yield |
| $Y_R$ | Reference Yield |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

The growing interest and increasing installation capacity of photovoltaic (PV) power plants have raised the awareness of the necessity and importance of better managing the PV power plant system in order to harvest the optimal energy yield from PV power plant. To accomplish above objectives, sufficient supervision and monitoring the health and performance of the PV system are necessary. In comparison to huge PV power plant, which can afford to have complicated PV monitoring systems and dedicated personnel available on site for continuous monitoring and maintenance, small-scale PV plants installed for residential or commercial and remote area usage are often insufficiently monitored after installation.

Setting up a remote monitoring system for a PV power plant enable the operators to have real-time monitoring to conduct data analysis on the performance of the system to give prominent to potential defects of the power supply design, hence permitting the use of proper countermeasures without being onsite. Among the benefits of remote monitoring systems for PV plants include (i) enabling PV plant operator to acquire real-time information of their PV panels with the corresponding economic advantage of making the ideal tradeoff by switching between electrical and solar power supply, (ii) instant problem pinpointing as well as preemptive resilience to failure enabling trained technician to fix the problem quickly, (iii) self- repairing of the PV system through monitoring software when possible [1].

## 1.2 PROBLEM STATEMENT

For small and medium-sized stand-alone PV power plants which are being set up in rural areas are normally operate unattended. As these PV power plants are installed away from the urban and easily accessible areas, repair and maintenance services on these PV power plants would be difficult, expensive and time-consuming. Technicians, who are responsible for these PV power plants need to be placed close to the geographical area of these PV power plants for continuous monitoring, maintenance, and repairing. Moreover, in some cases, the performance of the PV power plants could be degrading slowly after some time without over passing any defined threshold and without issuing any warning of this situation. Technician responsible would not be notified of such condition unless they have to continuously monitor the plant on-site or until it is too late for them to discover that the PV power plant has badly degraded or failed. Due to the reason above, stand-alone PV power plants installed in remote rural areas normally failed.

The PV power plant which installed at the UTP Solar Research Site is far away from the academic and student residential area, which would have faced the same problem as mentioned above. Parameters such as ambient temperature, wind speed, and energy yield of the PV power plant need to be monitored closely in order to evaluate its system efficiency. Hence, it would be ideal if the system could be monitored remotely. Remote accessing and monitoring enable the users to study the performance of the system without measuring the data on-site and able to monitor the system at all time.

## 1.3 OBJECTIVES

The objectives for conducting this project are as follows:

I. To set up the PV power plant system to be remotely monitored.
II. To make a parametric analysis of the performance of the PV power plant.

## 1.4 SCOPE OF STUDY

This project is conducted with the aim to set up a remote monitoring system to monitor the PV power plant in UTP. The energy yield of the PV power plant and the environment parameter such as wind velocity, ambient temperature, and insolation at the site will be monitored through Sunny Portal. With the collected environment parameter, we are able to derive the reference yield and the array yield, which can be used to compare with the final energy yield by the PV power plant and to evaluate the performance ratio of the PV power plant.

Besides, this project will also study the factors, which affect the performance ratio of the PV power plant. Factors such as module temperature, which can be derived with the consideration of environmental parameters; energy flow control mode of the system, and insolation are the key main factors that affect the performance of the PV power plant.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Energy is the essential driving force for development, modernization and economic foundation of our civilization and its demand is escalating globally. However, as current global energy sources primarily rely on burning fossil fuels, they have been the main contributing factors to the greenhouse emissions, global warming, and drastic climate change. Moreover, they are non-renewable and they will definitely end in the near future. The upraising concerns towards the environmental impact and depletion of available fossil fuels have driven the governments and industries from all over the globe to move towards green energy and producing energy from renewable energy sources, which are abundant and free to access.

As agreed by S. Mekhilef, A. Safari, W. Mustaffa, R. Saidur, R. Omar, and M. Younis (2012) [2], solar energy has always been considered as one of the most promising alternative energy. It is naturally available and a clean energy source, which is extracted from the sun and can be used directly to generate electricity. It has the least impact on the environment and will not deplete as natural fossil fuels do. Photovoltaic (PV) cells are used to capture the sun radiation and directly convert the sunlight into electricity. A PV module is a combination of PV cells and a PV array system is formed by connecting several PV module connected in series or parallel. Having the property to absorb sunlight, PV cells are able to capture photon and produce free moving electrons. As explained by K. L. Ray (2010) [3] , “when the electron gain sufficient energy from the sunlight and move freely in the PV cells, a potential barrier is built up and assists these free moving electrons to produce voltage, which is used to drive a current through the circuit”.

Malaysia is a tropical country and located in Southeast Asia, between the longitudes of 100 to 120 degree due East of Meridian and between 2 to 7 degree due North [4]. Due to the strategic location of Malaysia, high solar irradiance is available throughout the entire year. Nearly 88,467 MW of PV is installed in Malaysia in the year of 2014 [5]. S. C. Chua and T. H. Oh (2012) [6] anticipated that the future of solar energy is auspicious and is anticipated to outshine others renewable energy sources in Malaysia by the year of 2050 .

The growing interest and increasing installation capacity of photovoltaic (PV) power plants have raised the awareness of the necessity and importance of better managing the PV power plant system in order to harvest the optimal energy yield from PV power plant. To accomplish above objectives, sufficient supervision and monitoring the health and performance of the PV system are necessary. In comparison to huge PV power plant, which can afford to have complicated PV monitoring systems and dedicated personnel available on site for continuous monitoring and maintenance, small-scale PV plants installed for residential or commercial and remote area usage are often insufficiently monitored after installation.

Setting up a remote monitoring system for a PV power plant enable the operators to have real-time monitoring to conduct data analysis on the performance of the system to give prominent to potential defects of the power supply design, hence permitting the use of proper countermeasures without being onsite. Among the benefits of remote monitoring systems for PV plants include (i) enabling PV plant operator to acquire real-time information of their PV panels with the corresponding economic advantage of making the ideal tradeoff by switching between electrical and solar power supply, (ii) instant problem pinpointing as well as preemptive resilience to failure enabling trained technician to fix the problem quickly, (iii) self- repairing of the PV system through monitoring software when possible [1].

According to Santiago Manzano R. P.-O., David Guevara and Alberto Ríos (2014) [7], the analysis of remote monitoring projects and experience for PV installation and divide the architecture of a remote monitoring system into three layers, which are the Acquisition Layer, the Pretreatment and Record Layer and the Storage and Web Services Layer . N. Stroia, D. Moga, and Z. Barabas (2013) [8] agreed that web base technology is the most attractive for remote monitoring and control system. It allows operators to remote access to the PV system over the internet. However, the aspect of time delay, irregular data transition and data loss, and the problem of security of the system would raise concerns and should be thoroughly inspected [9] .

SMA Solar Technology AG (2011) [10] offers an internet base portal (Sunny Portal) for monitoring, visualization and presentation of plant data for plants equip with SMA communication products. Plant operators, installers and service technicians will have access to key data at any time and location. Default plant overview diagram are presented at the first access and can be customized to suit individual information such as plant description, graphs, images and texts for plant monitoring [10]. Sunny WebBox is a data logger, which allows remote monitoring and maintenance of large solar power plants, provide a variety of options for displaying, archiving and processing of data, and error alarming functions [11].

## 2.2 PV POWER GENERATION SYSTEM

There are two main types of PV power plant system available. They are the off-grid PV power plant system and on-grid PV power plant system. Off-grid PV power plant system operates independently whereas on-grid PV power plant system is connected to the national power grid. However, both system also consists of PV modules and have the ability to convert direct current (DC) to alternative current (AC) by using an inverter. The on-grid power plant has the need to convert the DC current output from the PV module to utility frequency AC current, a monitoring system, a transformer to deliver the generated electricity to the power grid and power lines for connecting the PV system to the power grid.

A PV power plant system is built up of many elements such as the PV cell, mechanical structure, electrical mountings and others in order to generate electricity from the sunlight irradiation [12]. Photovoltaic power generation system are normally a combination of PV module, batteries, inverters, charges, discharges controller, and other devices [13]. Some of the common equipment and their function are as stated below

I. **PV Module:** A PV module consists of numerous of PV cells. Photons are being captured by the cell material to produce pairs of electrons and holes when solar radiation is present in the day time. If the pairs of electrons and holes are near to the p-n junction, the electrons and holes will travel towards to the n-type junction side and p-type side, respectively. Current is produced when a load is connected to the two sides of the PV cells.

II. **Batteries:** Batteries are used to supply electrical power to the load when the solar power is not available and store the excess electricity produced by the PV power generation system.

III. **Charge and discharge controller:** It is also being referred as a bidirectional inverter. This device is used to manage and prevent overcharges and over discharges of the battery bank.

IV. **Inverter:** The inverter is used to convert DC current produced by the power plant to AC current. Square wave and sine wave inverters are available in the market [14]. Square waves inverters are generally being used for small projects and generate a power capacity of less than 100 W. They are low cost and simple but they are not in high demand as it utilize a harmonic system with a harmonic wave. Sine wave inverters are more expensive but can be utilized for different types of loads[15].

## 2.3 PERFORMANCE OF PHOTOVOLTAIC PLANT

According to A. Woyte, M. Richter, D. Moser, S. Mau, N. Reich, and U. Jahn (2013) [16], performance ratio (PR) is the most important quantity to be measured while evaluating the overall performance of a photovoltaic plant. There are several parameters including the site location, the climate and several loss mechanisms, which affect the performance of the power plant. There are two main plant losses, which were known as capture losses ($L_C$) and system losses ($L_S$). Capture losses occur due to the insufficient incoming light, temperature, electrical components mismatching, parasitic resistances in photovoltaic modules and poor maximum power point (MPP) tracking system whereas system losses are due to wiring, inverter, and transformer conversion losses [16]. A good PV system is designed to account for minimizing losses caused by a variety of system components. B. Decker and U. Jahn (1997) [17], is among the first to publish the empirical analyzes of losses in PV systems. B. Marion, J. Adelstein, K. Boyle, H. Hayden, B. Hammond, T. Fletcher, et al. (2005) [18], has given a thorough analysis of loss factors present in practice. The most influential causes for reducing the performance ratio of a PV plant are explained in the following paragraphs:

I. **PV Module Temperature**: The PV module performance will decrease as its temperature were raised. A solar module will heat up significantly when exposed to the solar irradiation, the module temperature may reach 80 °C with the present of air gaps to be used as natural ventilation [19].

II. **Dirt and Dust**: The PV module surface could be covered by dirt and dust which may create shade on the surface and block the full amount of sunlight striking on the module and hence reducing the output power. However, as the dust and dirt would only built-up in dry season, it is better to estimate a system output considering the reduction during dry periods. This is because as dirt and dust are often washed off during rain at normal day [16]. While often the soiling losses are low, for some locations, soiling can cause up to 70% of all losses [18].

III. **Wiring Losses and Connection Mismatch:** The total energy yield of the PV array is generally lower than the actual energy yield of individual modules. As studied by A.Woyteet.al (2013) [16] and J. Wong, Y. S. Lim, J. H. Tang, and E. Morris (2014) [20], the wiring mismatch from one module to the next module may contribute at least a 2 % loss in power system and result in the difference in the amount of energy yield . Ohmic resistance in the system wiring would also cause power loss. These losses should be minimized but it is hard to maintain these losses to be under 3% for the system [21].

IV. **Power Conversion Losses:** A minor amount of power generated will loss during the DC to AC power conversion process depending on the efficiency of the inverter. However, modern residential use a better PV inverter systems with peak efficiencies of up to 98% [16].

## 2.4 UTP POWER PLANT SYSTEM CONFIGURATION

The 10kWp PV power plant installed in UTP Solar Research Site consists of 40 pieces of PV panels from Canadian Solar, (Model:CS6P-250P). The UTP PV power generation system has two subarrays. One subarray with 2 parallel strings of 10 PV modules connected in series and connected to one PV inverter and another one with 10×2 linked the other inverter as illustrated in Figure 1. The PV modules are positioned in a fixed direction facing southwest at an inclined angle of 5°. Each of the PV modules consists of 60 solar cells which able to generate 250W. The details of the PV panel are shown in Table 1.

TABLE 1: Electrical Data of the PV Modules Provided by Canadian Solar Inc (2012) [22], Measured Under "Standard Test Conditions (STC) of Irradiance of 1000 W/m$^2$, Spectrum AM 1.5 and Cell Temperature 25 °C".

| STC | Canadian Solar CS6P-250P |
|---|---|
| Nominal Maximum Power, ($P_{max}$) | 250 W |
| Optimum Operating Voltage,($V_{mp}$) | 30.1 V |
| Optimum Operating Current, ($I_{mp}$) | 8.30 A |
| Open circuit Voltage, ($V_{oc}$) | 37.2 V |
| Short Circuit Current,($I_{sc}$) | 8.87 A |

The PV system utilizes two different types of inverters: two bidirectional inverters (SMA Sunny Island 8.0 H) and two PV inverters (SMA Sunny Boy 5000TL-21). The two PV inverters are connected to the PV arrays to convert the DC PV output to supply 230 $V_{AC}$ to the AC load and 48$V_{Dc}$ to a DC load while the remaining energy is used to charge the battery bank via the two bidirectional inverters.

The two bidirectional inverters are also connected to the load, PV inverters and battery bank. They have two functional modes, which are charging mode and discharging mode. They convert excess AC power generated by the inverters to DC and charge the battery bank during the charging mode. However, the inverters can also use the energy stored in the batteries to provide 230 $V_{AC}$ and 48 $V_{DC}$ output during the discharge mode. Thus, the connected loads can operate stably even when solar energy is not available and yet electricity demand still exists. The two parallel operation bidirectional inverters are operated in a master–slave-standby configuration. The battery tank comprises of 12 cells, divided into 3 section connected in parallel and in which 4 battery cells are connected in series to provide a 48$V_{DC}$ nominal storage voltage.

The environmental data such solar irradiation (W/m$^2$), ambient temperature (°C) and wind speed (m/s) are continuously recorded by the Sunny SensorBox and the operation performance data such as power output (kW), state of charge (SOC, %) as well as the electricity consumption at the intervals are recorded by Sunny Remote Control at an interval 1 minute.

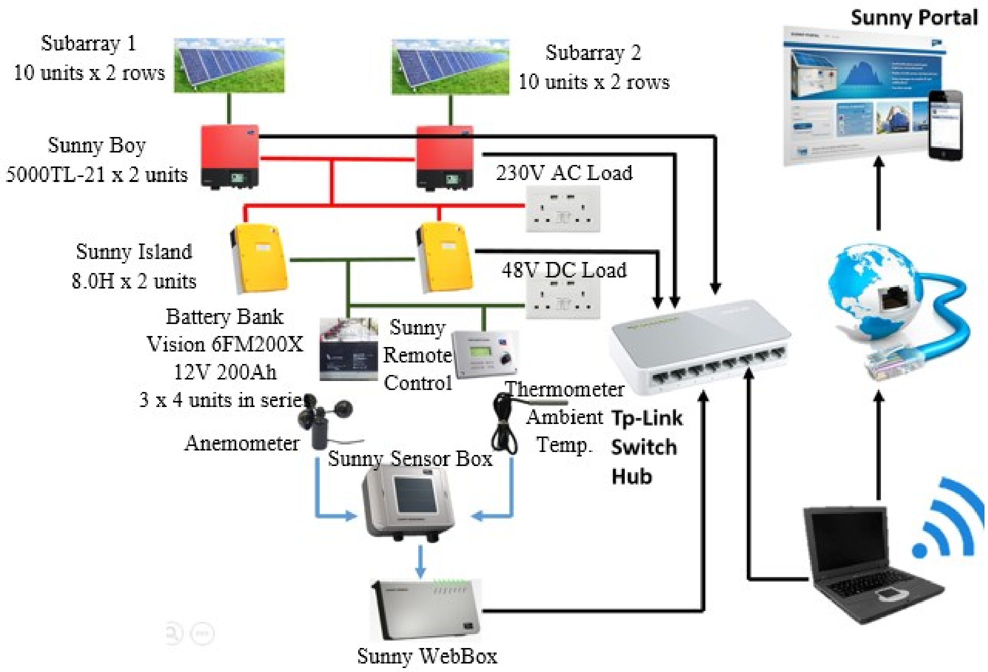



FIGURE 1: Schematic Diagram of the UTP PV Power Plant System

The details of the major components of the PV power plant are as follows:

I. **PV Modules:** The CS6P-250P Canadian Solar PV modules is a robust solar module with 60 solar cells. The modules are made from Poly-crystalline solar cells with the dimensions of 1638 mm x 982 mm x 40 mm. The system has 40 PV modules which covered an area of 64.34 m$^2$.

II. **PV Inverter:** The Sunny Boy 5000TL-21 PV Inverters are responsible for converting the DC power generated by the PV modules to AC power and to be supplied to load connected. 2 units of PV inverters are utilized in the plant to regulate maximum of 5 kW of power generation each. Its manufacturer claims that its “OptiTrac™ Global Peak features, SMA’s shade-tolerant MPP tracking algorithm, enable quickly adjusts to changes in solar irradiation, which mitigates the effects of shade and results in higher total power output and with two MPP trackers, the TL-21 series can ably handle complex roofs with multiple orientations or string lengths” [23]. As stated by the manufacturer, SMA America (2012) [10], “the inverters have Webconnect features embedded. One of its greatest advantages of having Webconnect features is that data is transmitted directly from the inverter to Sunny Places and Sunny Portal without the need for additional SMA devices”. Table 2 below show the electrical parameters of the PV inverters.

TABLE 2: Electrical Parameters of the PV Inverters by SMA America (2012)[10].

| Technical Data | Sunny Boy 5000TL-21 |
|---|---|
| Maximum DC Input Power | 5250 W |
| Maximum DC Voltage | 750 V |
| Maximum Input Current | 15 A |
| Nominal AC Output Power | 230 V |
| Maximum Apparent AC power | 5000 V |
| Maximum Output Current | 22 A |
| Maximum Efficiency | 96.5– 97 % |

III. **Bidirectional Inverter:** The Sunny Island SI 8.0H-11 battery inverters has the function of integrating the storage systems into stand-alone systems and into transmission or distribution grids. It saves the solar energy in the battery to provide it for use later. Its battery management features enable it to charge and discharge the connected battery automatically. 2 units of the bidirectional inverters is employed in the system. Table 3 below show the electrical parameters of the bi-directional inverters.

TABLE 3: Electrical Parameters of the Bi-directional Inverters by SMA America (2012)[10].

| **Technical Data** | **Sunny Boy 5000TL-21** |
|---|---|
| Rated Power | 6000 W |
| Rated DC Voltage Input | 48 V |
| Rated AC Voltage | 230 V |
| Maximum Output Current | 120 A |
| Maximum Efficiency | 96% |

IV. **Sunny Remote Control:** Sunny Remote Control offers conveniently commissioning and monitoring without the need to be in front of the inverter. It can run well at a distance of up to 20 meters and process information up to three Sunny Island devices. The rotary switch of the Sunny Remote Control allows user to have an intuitive operation. The current status of the system is displayed in only four-line displays and clearly arranged.

V. **Sunny WebBox:** The Sunny WebBox receives and save the latest measurement data and transmits them via RS485, allowing the system performance to be updated 24 hours per day. It allows quick reaction to be taken in the event of a problem. Parameters of the devices can be manipulated online and a variety of measured data can be evaluated, analyzed and downloaded by using a web browser from anywhere with an internet connection. All the measurement data collected from the connected devices is saved and transmitted to the Sunny Portal automatically.

VI. **Sunny Sensor Box:** The Sunny SensorBox can be used to measure the sun radiation and ambient temperature. It provides a real-time data comparison of plant performance in together with Sunny WebBox and Sunny Portal. This feature allows to detect shade, dirt, and gradually declining performance in a generator and thus maximizes yield security.

VII. **Battery Bank :** The battery bank consists of a total 12 units of batteries with a voltage rating of 12 V and discharge rate of 200 Ah. The batteries are divided into 3 section connected in parallel and in which 4 battery cells are connected in series to provide a $48V_{DC}$ nominal storage voltage. The batteries are being charged to the maximum of 92% instead of 100% to maximize their life span. The charging and discharging state of the batteries are being controlled and monitored by the bi-directional inverters (SMA Sunny Island 8.0H).

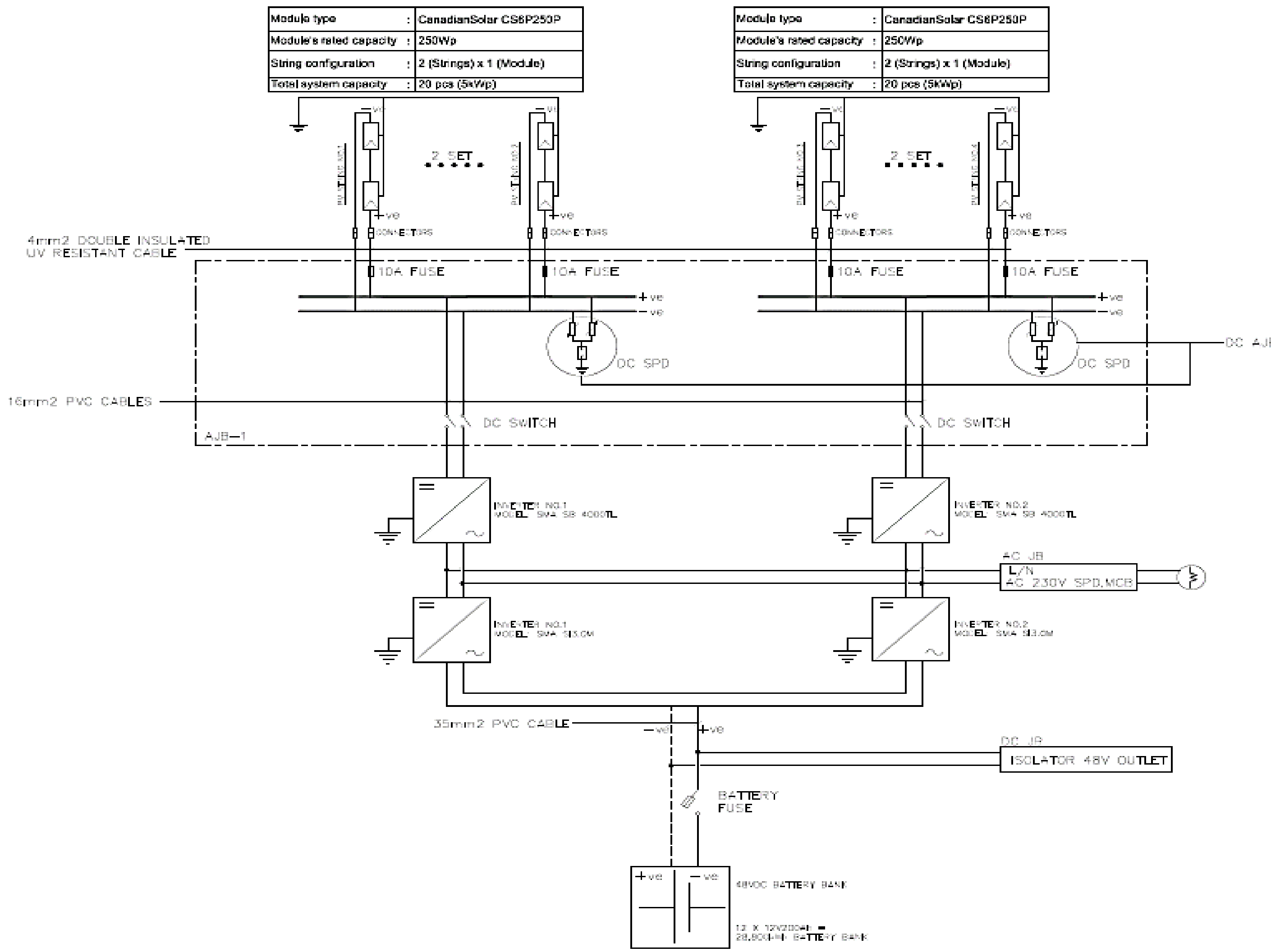



FIGURE 2 : The Schematic Block Circuit Diagram of the UTP PV Power Plant

TABLE 4 : Comparison of Different PV Power Plant Studies

| No | Author | Subject of Study | Findings |
| --- | --- | --- | --- |
| **1.** | E. Warnier, L. Yliniemi, and P. Joensuu (2003) [9] | Web-based Monitoring and Control | Web-based monitoring is an additional advantage to the current process control hierarchy. It provides plant operator a web-based platform, for remotely monitoring the behavior of process plants and controlling the plants. However, the main issue of web-based monitoring is the Internet time delay. When the Internet connection is not stable, the responses of the system may be delayed which lead to longer correction duration by the operator. As suggested by Egwin Warnier, Leena Yliniemi and Pasi Joensuu (2003) [9], "more advanced technologies should be implemented to properly deal with the Internet transmission delay" . |
| **2.** | Sasitharanuwat, A., Rakwichian, W., Ketjoy, N., & Yammen, S. (2007). [24] | Performance of A 10kWp PV Power System in Thailand | The silicon (SI) PV module has the highest power output and operating efficiency is varied linearly with insolation. |

| | | | |
|---|---|---|---|
| **3.** | B. P. Koirala, B. Sahan, and N. Henze (2009) [21] | MPP Mismatch Losses | The effect of mismatch losses of can be mitigated by using modern technologies such as active bypass, AC Modules and power optimization. |
| **4.** | E. Kymakis, S. Kalykakis, and T. M. Papazoglou (2009) [25] | Performance of PV Park on the Island of Crete | The PV park is able to produce 1336.4 kW h/kWp in 2007. |
| **5.** | M. Nkoloma, M. Zennaro, and A. Bagula (2011) [1] | PV Monitoring System in Malawi | M. Nkoloma, M. Zennaro, and A. Bagula (2011) [1] had built a sensor-based monitoring system around a PV power plant at Malawi primary school. The developed monitoring system imposed a lower management cost. |
| **6.** | Dubey, Swapnil Sarvaiya, Jatin Narotam Seshadri, Bharath (2013) [26] | Effect of Temperature on PV Production | As studied by Dubey, Swapnil Sarvaiya, Jatin Narotam,Seshadri, Bharath (2013) [26], PV cell performance decreases with increasing temperature, due to the increased internal carrier recombination rates, caused by increased carrier concentrations. |

| | | | |
|---|---|---|---|
| ***7.*** | Santana-Rodríguez, G,Vigil-Galan, O, Jimenez-Olarte, D, Contreras-Puente, G.,Monroy, BM, Escamilla-Esquivel, A (2013) [27] | Performance of A Grid-Connected PV system in Mexico City | Santana-Rodríguez, G et al. (2013) [27], suggest that with the installation of "100 photovoltaic systems per year with a capacity between 5 and 10 kW of installed power on roofs of governmental and non-governmental buildings, would represent an approximated production of 1752 MWh per year. Having 100 installed systems would be equivalent to saving 137 tonnes of petroleum per year, avoiding more than 744 tonnes of CO2 emissions."<br><br>Santana-Rodríguez, G et al. (2013) [27], recommend that amorphous silicon solar cells should be used if the operating temperature is in the range of 20 to 40 °C as it only loses 6% of its efficiency. |
| 8. | T. Ma, H. Yang, and L. Lu (2013) [28] | Performance of A Stand-alone PV System in Hong Kong | The average power yield from the PV system was 61.2 kW h/d. The efficiency of the PV power plant decreases with the increase in cell temperature. The authors agreed that low load and mismatch are the main reasons lead to a decrease in performance ratio of the plant. |
| ***9.*** | Tina, G. M., & Grasso, A. D. (2014) [29] | Remote Monitoring System for Stand-alone PV Power Plants | According to Tina, G. M., & Grasso, A. D. (2014) [29],the remote monitoring system is useful to detect "operational problem, soiling of |

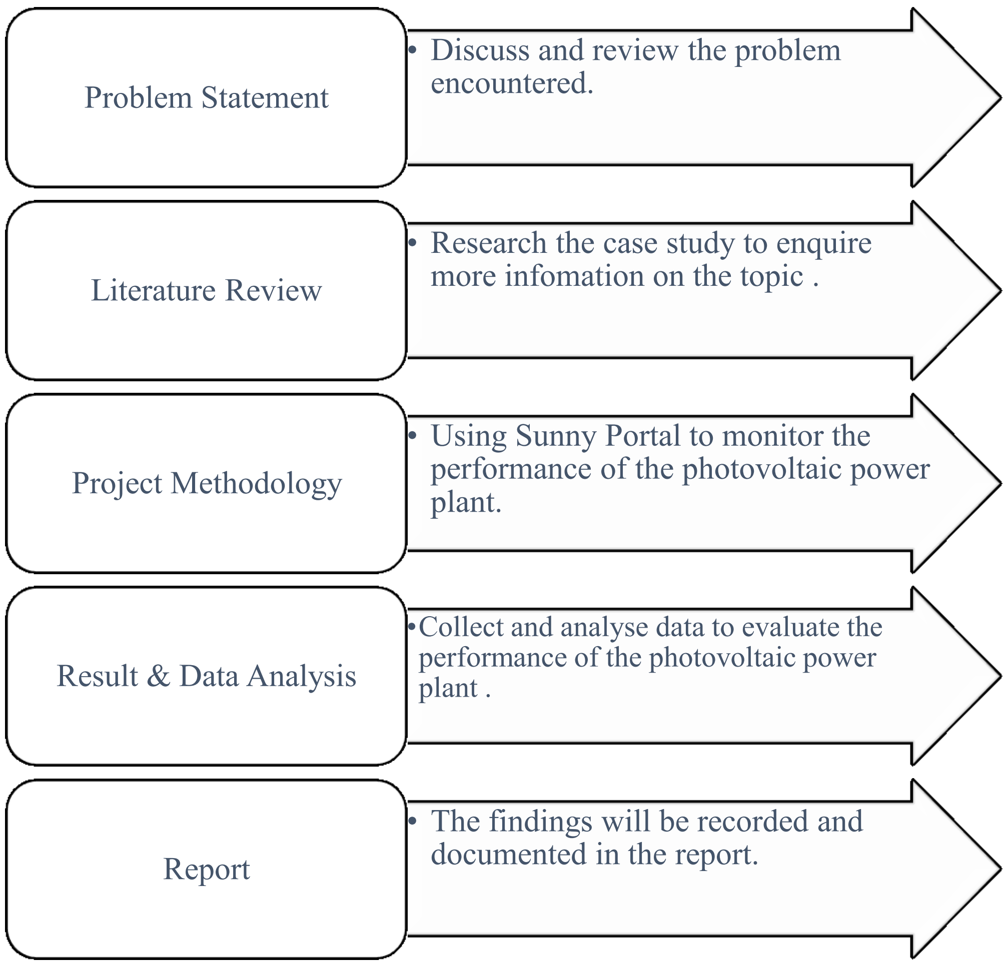
| | | | |
|---|---|---|---|
| | | | PV modules, the high temperature of the batteries, detaching of the sensors”. |
| ***10.*** | A. El Fathi, L. Nkhaili, A. Bennouna, and A. Outzourhit (2014) [30] | Performance of A Stand-alone PV Power Plant | The performance ratio of the PV power plant depends strongly on the energy demand on the state of charge (SOC) of the battery bank. The performance ratio of the PV power plant varied between 33.5% to 70.2% as indicated in [30]. |

# CHAPTER 3

# METHODOLOGY

## 3.1 RESEARCH METHODOLOGY

The following is the flow chart planned for conducting this project:



## 3.2 KEY MILESTONE and GRANT CHART

| No. | Details/ Week | FYP 1 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1 | **Title Selection**<br>- Meeting with SV<br>- Study the topic given | | | | | | | | | | | | | | |
| 2 | **Literature Review**<br>- Study the literature review on the PV system and its components.<br>- Study the electric parameter of the UTP PV power plant system components<br>- Study the difference and method of connection of each PV system components<br>- Purchase necessary connection components | | | | | | | | | | | | | | |
| 5 | **Project Work & Study**<br>- Setting up and configure the connection of the components. | | | | | | | | | | | | | | |

| No. | Details/ Week | FYP 2 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1 | **Data Collection**<br>-Monitor and collect data from the PV system. | | | | | | | | | | | | | | |
| 3 | **Perform System Analysis**<br>- Producing graphs and diagram<br>- Analyze the data collected from the system.<br>- Discuss and conclude the finding of the project | | | | | | | | | | | | | | |

Key Milestones

## 3.3 PROJECT METHODOLOGY

### 3.3.1 Methods of Setting Up the Remote Accessing for PV Plant System

The PV inverters, bidirectional inverters, Sunny SensorBox, Sunny Webbox and the laptop are all connected to the Ethernet switch together by WLAN cables as shown in Figure 1. The laptop is connected to an internet broadband device for internet access. A bridge connection is created between the laptop and the Ethernet switch which enables internet access sharing to all other device connected to the Ethernet switch. Besides, by using the Ethernet switch, the laptop can be used to access the configuration interface of each device. Different Internet Protocol (IP) addresses are assigned to devices. By determining the default gateways and Domain Name System (DNS) of the broadband device, and configure the same values to the devices to enables them to access the internet. When all the devices are configured with the correct internet connection setting, they are able to access the internet and to be registered on Sunny Portal.

Through the Sunny Portal, the following parameters will be monitored in real time:

TABLE 5: Parameters Monitored in Real Time

| **Parameters** | **Unit** |
|---|---|
| Insolation | W/m^2 |
| Wind Velocity | m/s |
| Ambient Temperature | °C |
| PV Array Output Power | kW |
| State of Charge (SOC) of Battery | % |

| | |
|---|---|
| Inverter Frequency | Hz |

### 3.3.2 Methods of Evaluation

The system performance of the UTP PV power plant is evaluated based on the power generated by PV arrays, inverters and the SOC of battery bank of the PV plant. Normalized parameters and energy performance indices (efficiencies/ratio) were used to evaluate the overall performance of the system [28]. Tao Ma and Hongxiang Yang (2013) [28] suggest that the normalized performance parameters are commonly used as indicators to compare different PV systems' performance. These indicators in units of kWh/kWp/d are calculated by relating the energies used to the nominal power of the PV array. These parameters are analyzed according to the guideline of IEC Standard 61724 [31].

The PV cell operating temperature, $T_C$ of the PV panels are not being measured by using any sensor attached to the PV panels as the data logger is located out of the range of effective transmission and accuracy of the measurement would be affected. Yet it is an important parameter to evaluate the performance of a PV system.

According to J. A. Duffie, W. A. Beckman, and W. Worek (1994) [32], the cell temperature of the PV panels was estimated by using the following equation:

$$T_c = \left(T_{NOCT} - T_{a,NOCT}\right)\left({G_T}/{G_{NOCT}}\right)\left({9.5}/{5.7 + 3.8V}\right)\left(1 - {\eta_C}/{\tau\alpha}\right) \quad (1)$$

where:

the nominal operating cell temperature (NOCT) is defined as the cell or module temperature that is reached when the cells are mounted in their normal way at a solar radiation level of 800

W/m$^2$, a wind speed of 1 m/s, an ambient temperature of 20°C, and no-load operation;

$\tau\alpha$ in the last term is not generally known, but an estimate of 0.9 can be used without serious error since the term $\eta_C/\tau\alpha$ is small compared to unity;

V is the local wind speed in meters per second.

Array Yield ($Y_A$) is defined as the number of hours per day that the array would need to operate at its nominal power, $P_0$ to contribute the same quantity of energy to the system [28] . It is the annual or daily energy output by the system divided by the peak power output as the equation stated below [25] :

$$Y_A = E_A/P_0 \ \left(kW\ h/kW_p\right) \tag{2}$$

where:

$E_A$ is the hourly array energy output ($kW\ h$);

$P_0$ is the PV array peak power ($kW_p$).

Final yield ($Y_f$) is referred as the usable amount of energy derived from the entire PV power generation system. The yield is delivered to the load per kilowatt peak of installed photovoltaic array.

According to T. Ma, H. Yang, and L. Lu (2013) [28] , it is stated as:

$$Y_F = E_{PV}/P_O \ \left(kW\ h/d/kW_p\right) \tag{3}$$

where:

$E_{pv}$ is the actual energy amount delivered to the load by the PV system;

$P_0$ is the PV array peak power ($kW_p$).

Reference Yield ($Y_r$) is defined as the ideal amount of energy produced by the PV plant, which is also defined as the expected output from the same system with nominal efficiency determined under Standard Test Conditions (STC) of PV modules[28]. It is derived as:

$$Y_R = A.\eta_{STC}.\int G_i dt/P_0 \ \left(kW\ h/kW_p\right) \quad (4)$$

where:
A is the total area of the PV array ;
$G_i$ is the irradiance incident on the tilted PV array ($W/m^2$);
$\eta_{STC}$ is the nominal efficiency of the PV module at STC according to the specification provided by the manufacturer.

Energy losses show the amount of time during which the array would be required to operate at its nominal power, $P_0$ to produce power for the losses [28]. The losses mainly include the two parts: system losses ($L_s$) and array capture losses ($L_c$). The equation to calculate system losses and array capture losses are as follow [28] :

Capture Losses:

$$L_c = Y_R - Y_F \quad (5)$$

System Losses:

$$L_s = Y_A - Y_F \quad (6)$$

The performance ratio, PR is defined as when the $Y_f$ compares against with the $Y_r$. With the expected output of power generation by considering the amount of insolation of the system received compare against the actual power generated by the system. It accounts for the overall effect of losses on the rated output due to inverter inefficiency, wiring mismatch, and other losses such as transforming the DC. to A.C. power, PV module temperature, incomplete use of irradiance because of the reflection from the module top surface; soiling; snowing; system downtime; and component failures [28] . It is stated as:

Performance Ratio:

$$PR = Y_f / Y_r \tag{7}$$

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 SUNNY PORTAL MONITORING SYSTEM

As both the Sunny Webbox and Sunny Boy 5000TL-21 Inverters are embedded with Webconnect function, they are able to transmit data recorded to Sunny Portal, which can be accessed through https://www.sunnyportal.com as shown in Figure 3 when internet access is available.

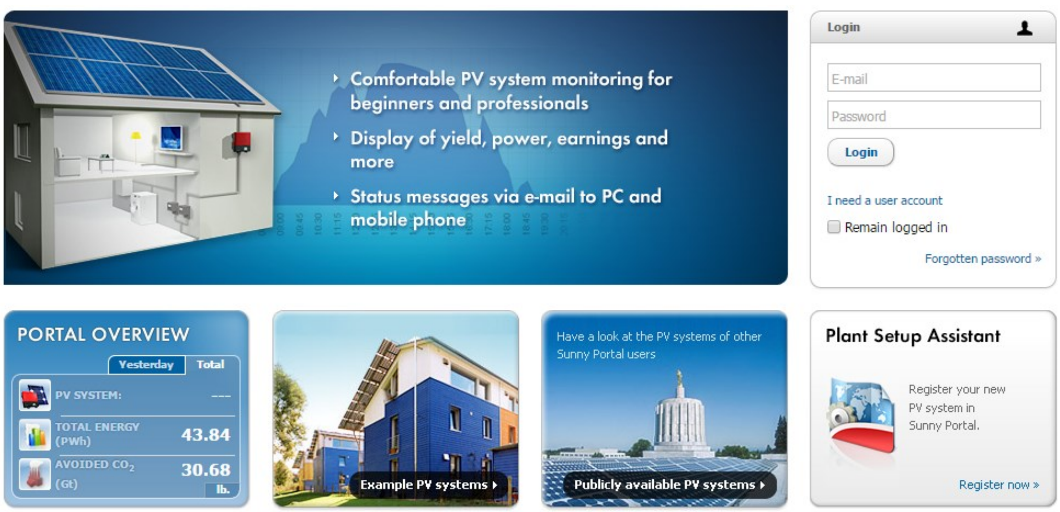



FIGURE 3: Login Page of Sunny Portal.

The access to the data recorded of the power plant is only limited to 2 different access point simultaneously with the correct username and password for security purposes. Any attempt of more than 2 different access point simultaneously will force the system to log out one of the previous access.

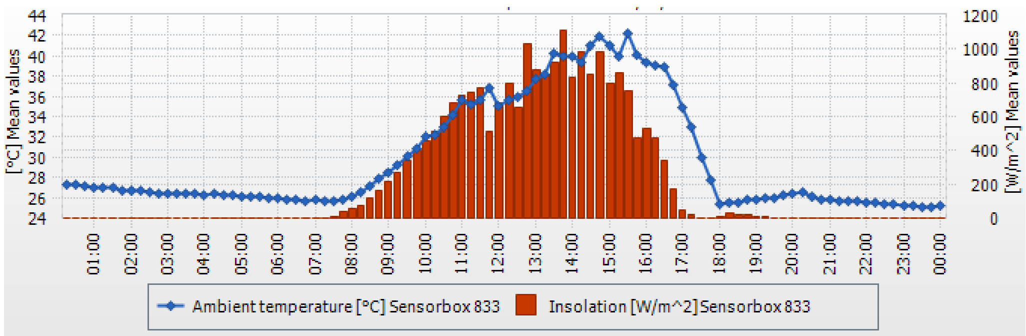



FIGURE 4: Insolation VS Ambient Temperature on a Specific Day

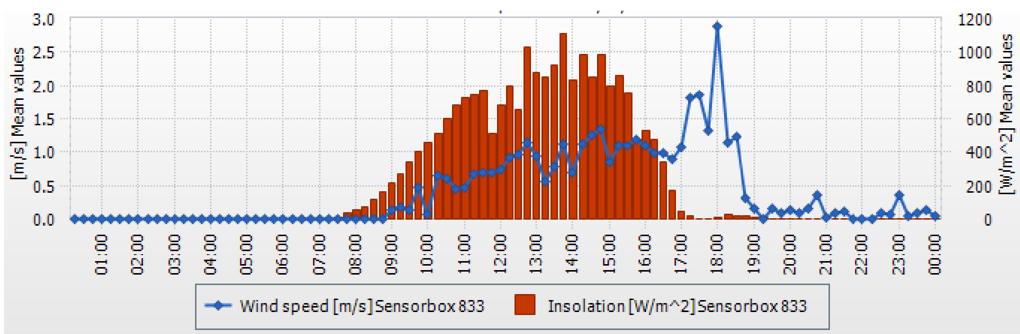



FIGURE 5: Wind Speed VS Insolation on a Specific Day

Figure 4 and Figure 5 show the graphs of insolation versus ambient temperature and wind speed versus insolation recorded by Sunny Portal respectively on a specific day. The details data can be downloaded in CSV. format. Figure 6 and Figure 7 show the graph of power generated a specific day and the diagram of the total yield of a specific month respectively.

We can observe that in Figure 7, there are gaps between the bar diagrams. These gaps are formed due to incomplete data transmission or data are lost due to the instability of internet connection. The current internet connection is provided via a broadband device. The broadband device has a poor and slow internet connectivity at the UTP Solar Research Site, which leads to loss of data during the transmission. The slow and poor internet connectivity cause delay of data transmission of the devices and their response time is taking too long for the SMA Germany servers to make a respond and collect the data transmitted over.

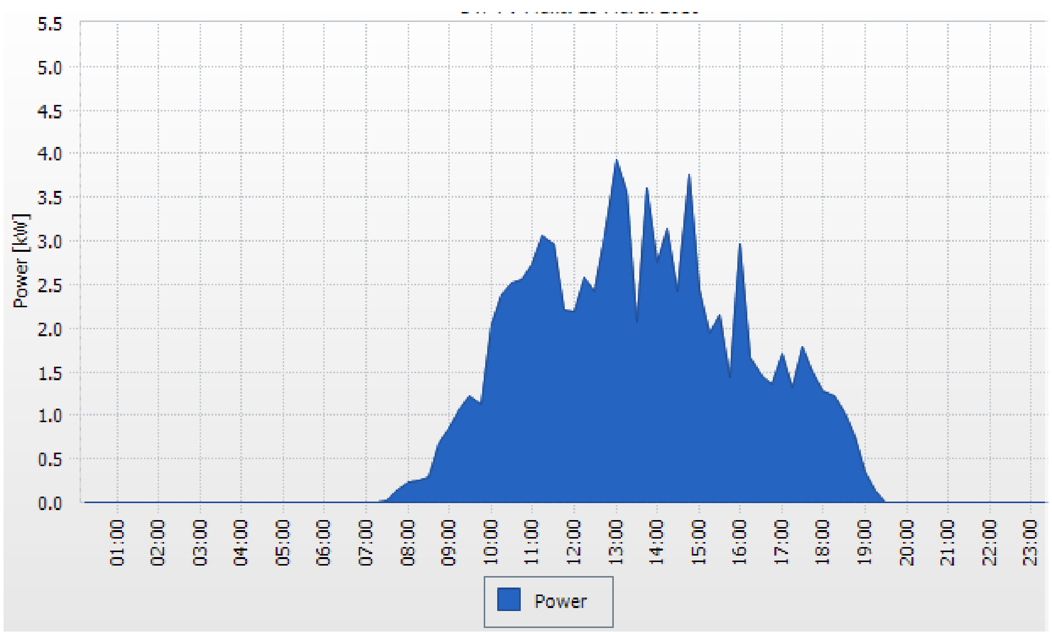



FIGURE 6: Power Generated on a Specific Day

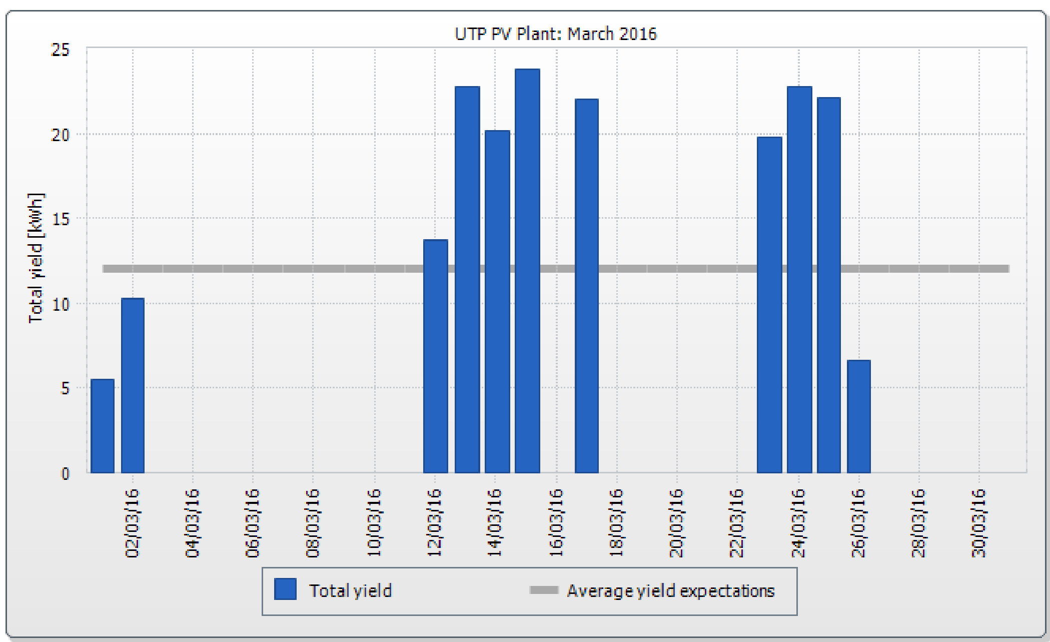



FIGURE 7: Total Yield of a Specific Month

## 4.2 PV ARRAY PERFORMANCE ANALYSIS

Figure 8, 9 and 10 show the active power output of the SMA Sunny Boy PV inverters and the global irradiance for a cloudy day, which noted as Day 1, a mid-cloudy day noted as Day 2 and sunny day noted as Day 3. It can be observed that the sun radiation is only available at around at 0745 and stop at around 1945 for the three specific days. As the insolation level of Day 1 is fluctuating greatly, it is classified as a cloudy day. However, the insolation level is low before 1400 on Day 2 indicating that it is mid-cloudy but the sky is clear out in the afternoon with the increase of insolation level detected. As expected from a sunny day, Day 3 has a smooth bell-shaped insolation curve as being shown in Figure 10.

From the figures, we can observe that the active power generated do not follow the instantaneous changes in the insolation for the days especially on Day 3 due to the power regulation control by the bidirectional inverter. As can be observed from Figure 10, Day 3 has a sharp drop of active power generation after 1050 while the insolation level after 1050 is high. As discuss in [28], in spite of the high levels of insolation, the observed drop in the active power generation is due to the way the battery inverter managed the frequency of the power generation system. As we will see in the following section, the PV inverters are instructed through changes in the grid frequency to reduce their output power when the state of charge (SOC) of the battery is high and the demand from the households is low during the daytime.

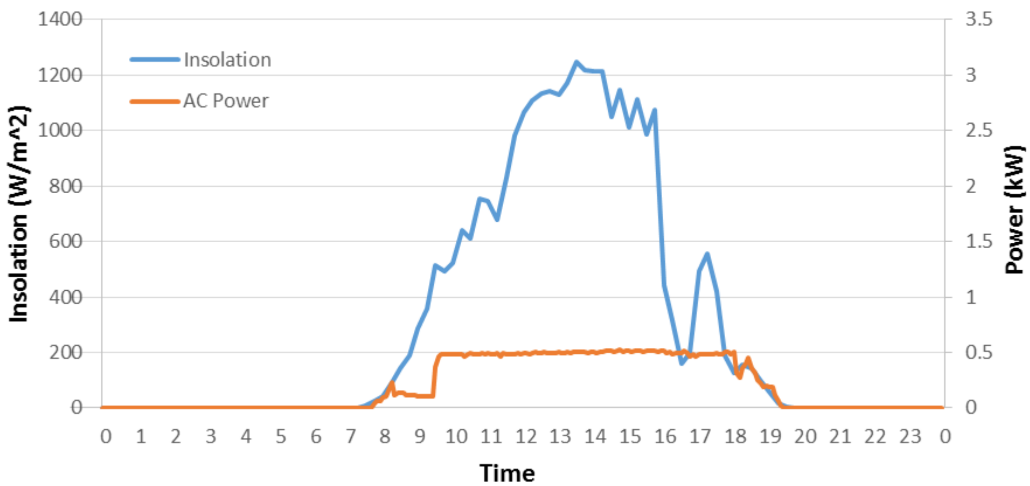



FIGURE 8: AC Power Output VS Insolation for Day 1.

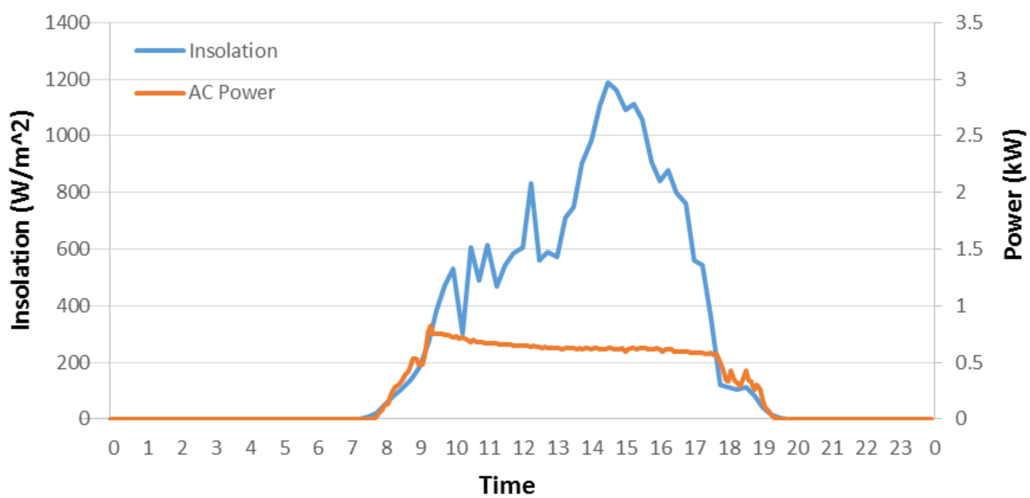



FIGURE 9: AC Power Output VS Insolation for Day 2.

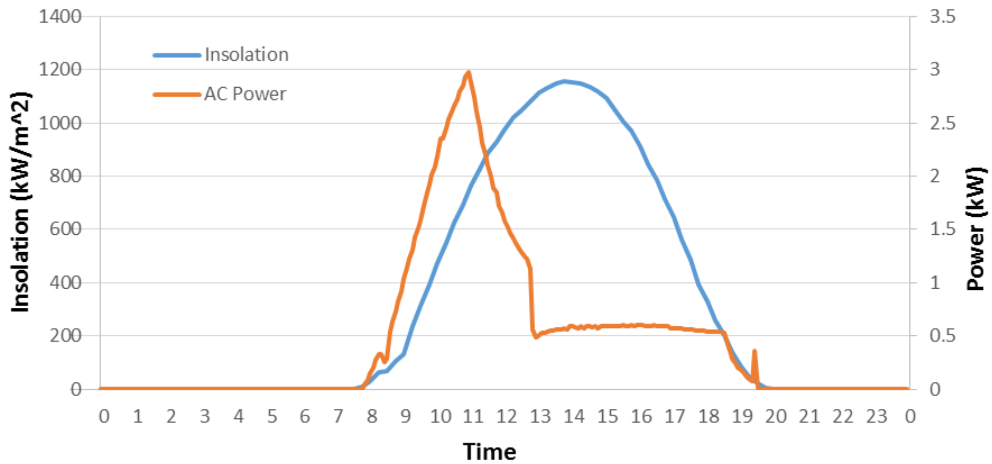



FIGURE 10: AC Power Output VS Insolation for Day 3.

## 4.3 EFFECT OF TEMPERATURE ON PERFORMANCE RATIO

As discuss in [3, 25, 26, 28], temperature plays an important role in decreasing the performance ratio of PV power plant. As we can observe in Figure 11, 12 and 13, when the temperature is high the performance ratio of the power plant drop drastically. The performance ratio decreases when the cell temperature is higher of 32°C. Although the insolation level is high around 1300 to 1600, the performance ratio is the lowest. As discuss in [26], the high cell temperature would increase the PV carrier concentration which leads to the decrease in PV performance. Hence, S. Dubey, J. N. Sarvaiya, and B. Seshadri (2013) [26] suggest that PV modules should be installed in the region with higher altitude to have higher performance ratio due to low temperature.

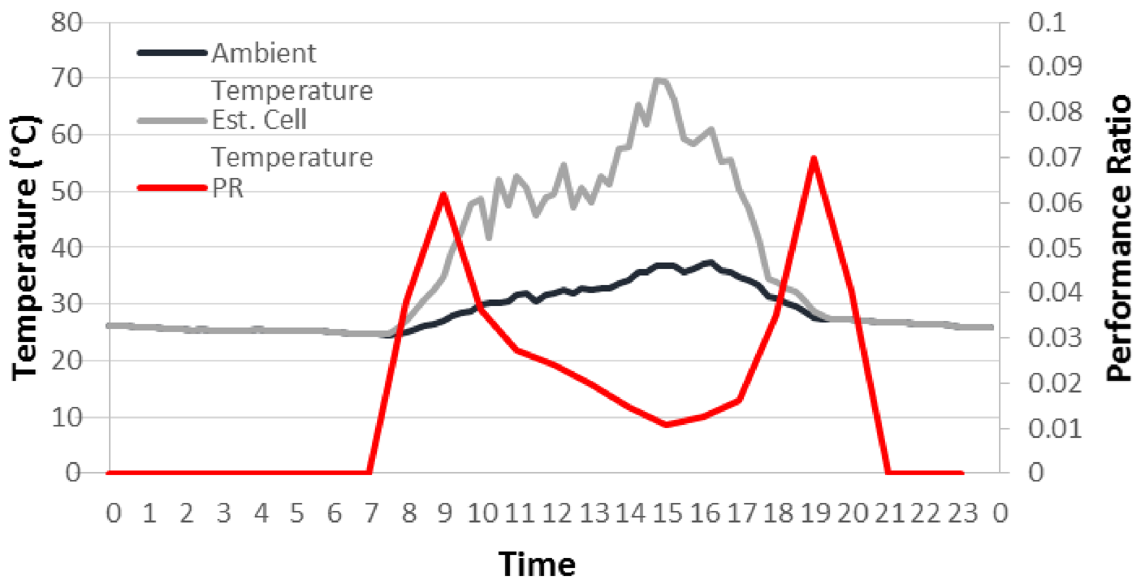



FIGURE 11: Temperature VS Performance Ratio for Day 1.

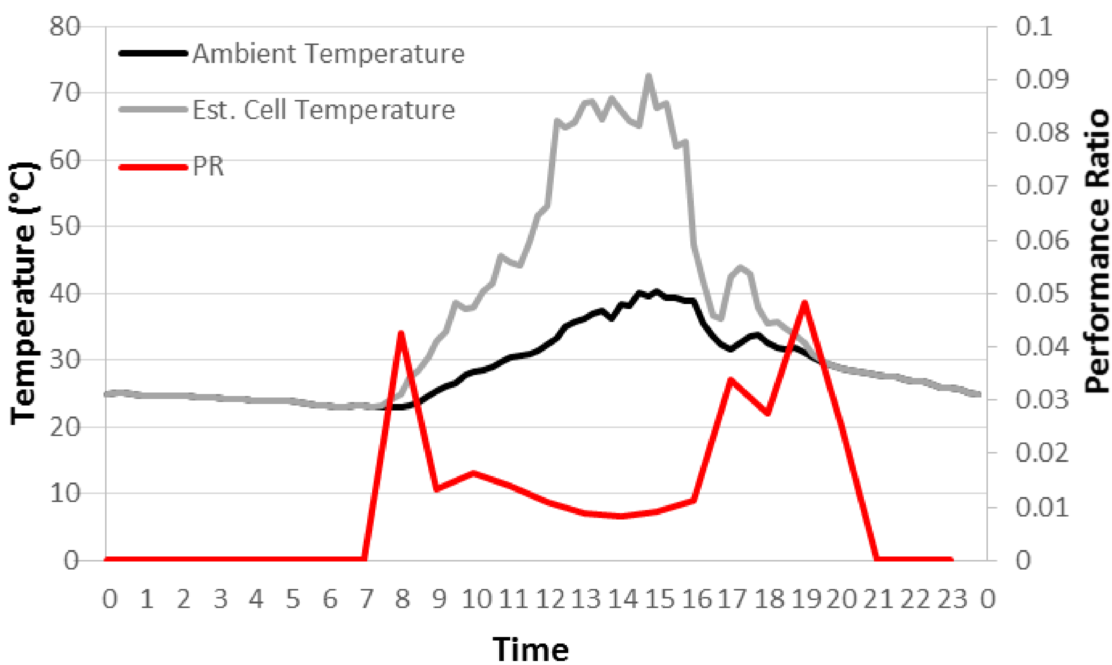



FIGURE 12: Temperature VS Performance Ratio for Day 2

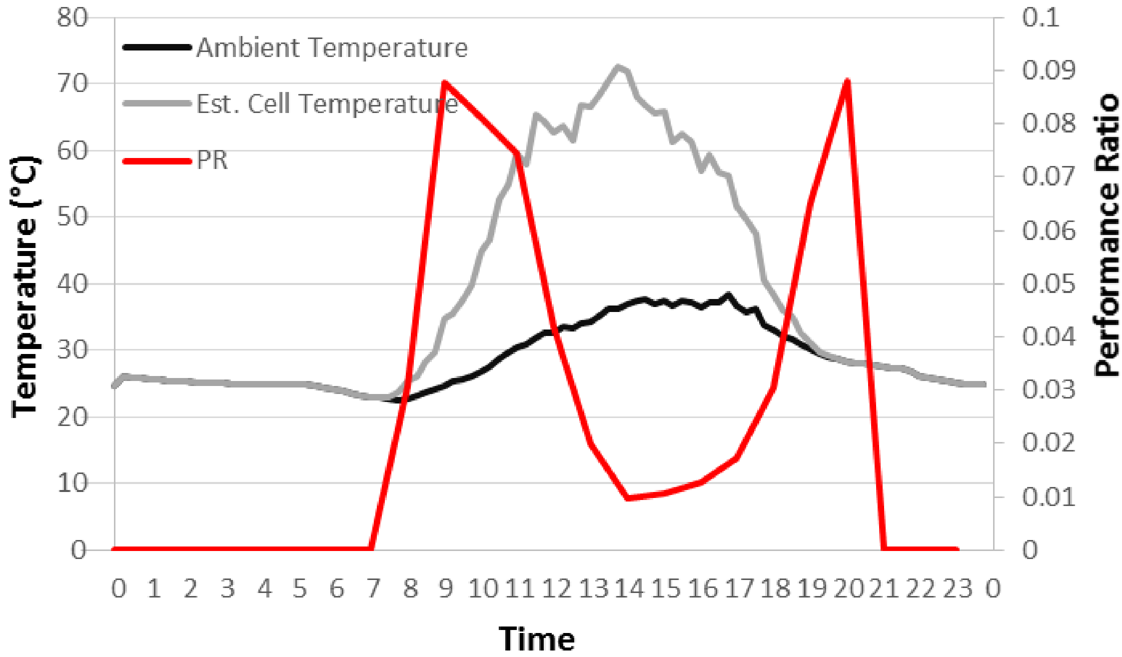



FIGURE 13: Temperature VS Performance Ratio for Day 3

## 4.4 EFFECT OF POWER MANAGEMENT MODE ON PERFORMANCE RATIO

The bidirectional Sunny Island inverters are responsible for the power management of the PV plant system. The bidirectional inverters regulate the power flow of the system by using droop mode control [33, 34]. Jaehong Kim, Josep M. Guerrero, Pedro Rodriguez, Remus Teodorescu and Kwanghee Nam (2011) [34], states that droop control is widely considered to be a good choice for managing the power flows between micro-grid converters in a decentralized manner. Using this mode of control, the bidirectional inverters are able to vary the grid frequency depending on its active power [34] as can be observed in Figure 14. The figure presents the battery bank SOCs (Figure 14.a), the AC power generated by one of the PV-inverter (Figure 14.b) and the frequency (Figure 14.c) for Day 3.

As discussed in [34], with the droop mode control, the bidirectional inverter will raise the frequency of the system when there was more solar energy is present than the load required and the batteries are fully charged whereas the bi-directional inverter will lower the grid frequency if less solar energy is present than the load is in demand and the batteries are not fully charged to trigger the inverters to raise the energy output.

As can be observed in Figure 14, the SOC of the battery is low as the batteries are discharged at the previous night, the bidirectional inverters lowered the grid frequency of the system to 49 Hz to trigger the system to generate AC power once the solar energy is available. While the solar energy is available and the batteries are being charged, the bidirectional inverters start to raise the frequency of the system. As the SOC of the batteries has reached around 91 %, the bidirectional inverters raise the system frequency to 51 Hz to limit the power flow. This occurred between 12 h and 18 h for this day and made the PV inverters to reduce their output power in response to this increased frequency as shown in Figure 14.

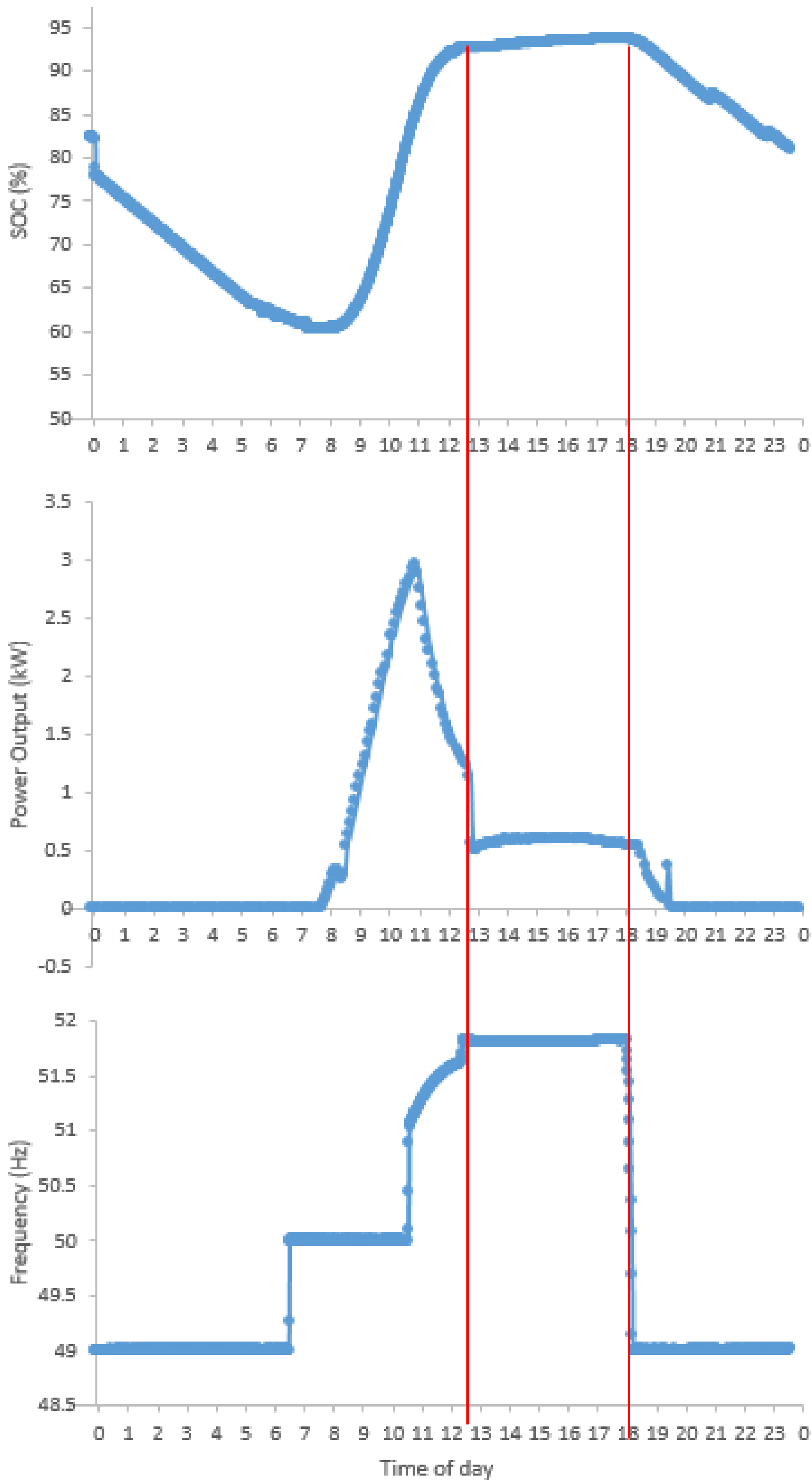



FIGURE 14 : (a) SOCs of Battery Bank, (b) The AC Power Generated and (C) the Voltage Frequency For Day 3.

## 4.5 THE ACCURACY OF INTEGRATED SOLAR RADIATION SENSOR

The Sunny SensorBox is equipped with an amorphous silicon (aSi) cell as a solar radiation sensor to detect the insolation level at the UTP Solar Research Site. As we can observe in Figure 8, 9 and 10, the insolation level detected is reaching 1200 W/m$^2$. This high insolation level is hard to be reached in Malaysia. In order to validate the accuracy of the insolation level detected by aSi cell, a comparison of insolation reading is made by using another two pyrometers, which Pyranometer 1 are measuring direct solar irradiance and Pyranometer 2 measuring global insolation for Day 1, Day 2 and Day 3 as can be shown Figure 15, 16 and 17. The insolation level detected by using a-Si cell is 6%-15% higher than the Pyranometer 2 between 1000 to 1700.

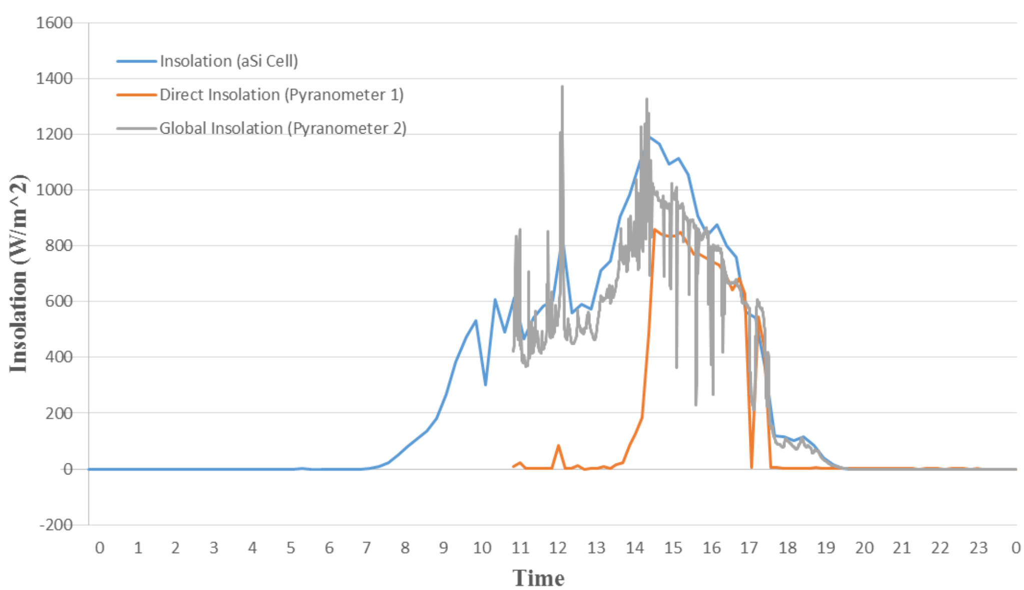



FIGURE 15: Insolation VS Time for Day 1

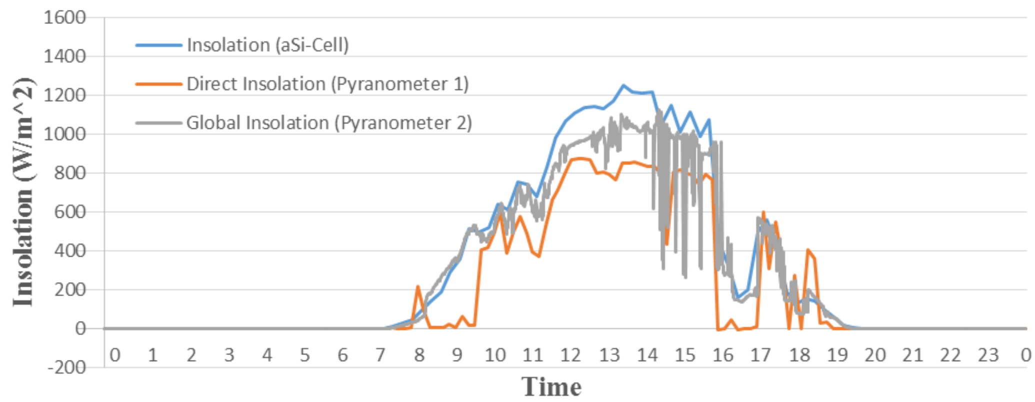



FIGURE 16: Insolation VS Time for Day 2

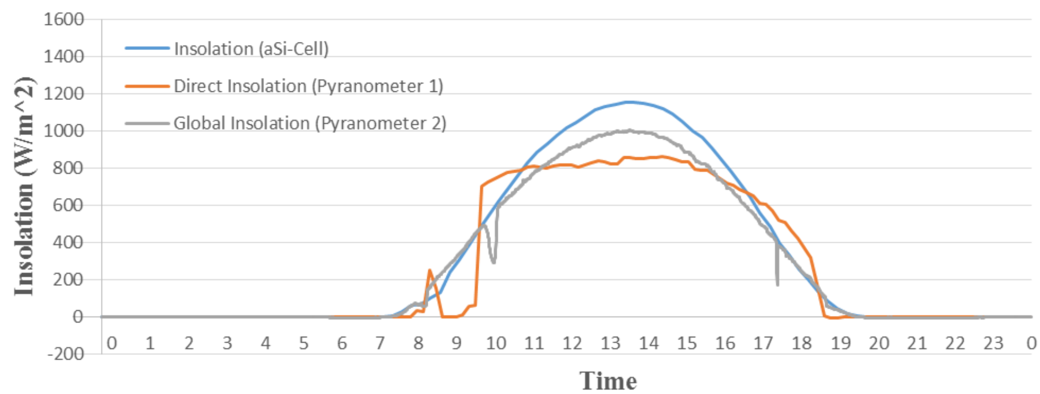



FIGURE 17: Insolation VS Time for Day 3

## 4.6 OVERALL SYSTEM PERFORMANCE

From Table 6, we can observe that the performance ratio of the PV plant is low. The performance ratio of the inverters varies only between 12.90 % to 29.74 %. The total power fed to the PV system is the highest for Day 3. As the power losses are the lowest on Day 3, most of the power generated by the PV system is used to charge the battery bank and consumed by the load. In spite of having the highest reference yield and array yield, Day 2 also experienced the largest amount of power loss, which results in having the lowest performance ratio (PR) of only 12.90 %. In the contrary, the mid-cloudy day, Day 1 has the lowest reference yield and array yield, yet it has obtained a higher performance ratio than Day 2.

TABLE 6: AC Power generated, yields and loss parameter for the specific days

| | E (kWh) | $Y_R$ (h) | $Y_A$ (h) | $Y_F$ (h) | $L_S$ (h) | $L_C$(h) | $L_C$+$L_S$ (h) | PR (%) |
|---|---|---|---|---|---|---|---|---|
| **Day 1** | 12.82 | 6.33 | 6.04 | 1.28 | 4.76 | 0.29 | 5.05 | 20.26 |
| **Day 2** | 9.50 | 7.33 | 6.91 | 0.95 | 5.97 | 0.42 | 6.38 | 12.90 |
| **Day 3** | 22.763 | 7.72 | 7.19 | 2.29 | 4.90 | 0.52 | 4.78 | 29.74 |

Where:

| | |
|---|---|
| E | Generated Power |
| $Y_R$ | Reference Yield |
| $Y_A$ | Array Yield |
| $Y_F$ | Final Yield |
| $L_S$ | System Loss |
| $L_C$ | Array Capture Loss |
| $L_S$+$L_C$ | Total Loss |
| PR | Performance Ratio |

The low values of the PR achieved for the days are mainly due to the drop in the power fed to the system as shown in Figure 14 as a result of the way the activated power are regulated by the bidirectional inverter. The drop will start when the SOC of the battery have almost reached its maximum value as shown in Figure 14.b and Figure 14.c. At this instance, the bidirectional inverters raise the frequency of the system as shown in Figure 14.c and the PV inverters will start to reduce its AC power generation as a consequence. We can also observe the same trend of effect on power regulation as discussed in [30, 33].

However, as discuss in [3, 32], the cell operating temperature could also be one of the many factors that affect the performance of the power plant. According to the PV module manufacturer, the module efficiency would drop – 0.43 %/ °C when the cell operating temperature are above 45°C [22].

From these observations, we conclude that for this local grid control mode, the PR of the PV plant depends not only on the losses of the system such as array, inverts, wires and others but also mainly on the state of charge (SOC) of the battery bank, the energy demand of the loads and the cell temperature.

# CHAPTER 5

# CONCLUSIONS & RECOMMENDATION

This aim of this project is to set up an online monitoring system to monitor the photovoltaic power generation system remotely and make a thorough analysis to evaluate the performance of the system. Setting up an online monitoring system could ease the researchers to study and monitor the performance of the photovoltaic power generation system. The students would not be required to be on-site to record data, as the data could be recorded by the data logging device, Sunny WebBox at all time. The data collected by the Sunny WebBox will be transmitted to the Sunny Portal. Students are then able to view the data collected on Sunny Portal.

This paper presented a remote PV plant in UTP to be monitored remotely. The performance parameters of the plant are evaluated from the monitored data. It is observed that the yields and consequently the performance ratio of the plants depend strongly on the energy demand as well as on the state of charge of the battery. This is a consequence of the method used to control the energy flow in the local grid. The performance ratio of the plant varied between 12.90% and 29.74%. The low PR value of the system is mainly due to the system losses. Fathi, A El; Nkhaili, L; Bennouna, A; Outzourhit, A (2014) [30] suggest that this parameter will be further improved by using all the available PV energy through the use of a dump load such as mechanical pumps or motors.

It is recommended that the PV power plant should be monitored for a year in order to have a better evaluation of its performance. The PV system would also be connected to a DC and AC loads instead of just AC load alone so that we can better determine the performance of the battery bank and the inverters. Factors such as shading and wiring mismatch should be further studied as they are not covered in this project. As suggested in [35], pyranometer or crystalline silicon reference sensors should be used to compare the insolation reading detected by the a-Si cell . A stable internet connection device such as a modem or WLAN connection should be installed at the UTP Solar Research Site instead of using broadband as a mean for internet connection.

## REFERENCES


[1] M. Nkoloma, M. Zennaro, and A. Bagula, "SM 2: Solar monitoring system in Malawi," in *Kaleidoscope 2011: The Fully Networked Human?-Innovations for Future Networks and Services (K-2011), Proceedings of ITU*, 2011, pp. 1-6.

[2] S. Mekhilef, A. Safari, W. Mustaffa, R. Saidur, R. Omar, and M. Younis, "Solar energy in Malaysia: current state and prospects," *Renewable and Sustainable Energy Reviews,* vol. 16, pp. 386-396, 2012.

[3] K. L. Ray, "Photovoltaic cell efficiency at elevated temperatures," Massachusetts Institute of Technology, 2010.

[4] S. S. a. A. M. omar, "The Malaysian Building Integrated Photovoltaic Project: Country Report."

[5] S. E. D. A. Malaysia, "National Survey report of PV Power applications in MALAYSIA 2014," 2014.

[6] S. C. Chua and T. H. Oh, "Solar energy outlook in Malaysia," *Renewable and Sustainable Energy Reviews,* vol. 16, pp. 564-574, 2012.

[7] R. P.-O. Santiago Manzano, David Guevara, Alberto Ríos, "An Overview of Remote Monitoring PV System: Acquisition,Storage, Processing and Publication of Real-Time Data Based On Cloud Computing," Facultad de Ingeniería en Sistemas, Electrónica e Industrial Universidad Técnica de Ambato, 2014.

[8] N. Stroia, D. Moga, and Z. Barabas, "Web based monitoring of solar power systems," in *Convergence of Information Technologies and Control Methods with Power Systems*, 2013, pp. 131-136.

[9] E. Warnier, L. Yliniemi, and P. Joensuu, "Web based monitoring and control of industrial processes," ed: Report A, 2003.

[10] L. SMA America. (2011). *Sunny WebBox and Sunny WebBox with Bluetooth Wireless Technology in SUNNY PORTAL. User Manual.* Available: http://www.smaamerica.com/

[11] L. SMA America, "Device for Plant Monitoring SUNNY WEBBOX. User Manual.," ed.

[12] B. Parida, S. Iniyan, and R. Goic, "A review of solar photovoltaic technologies," *Renewable and sustainable energy reviews,* vol. 15, pp. 1625-1636, 2011.

[13] H. Jin, L. Qin, C. Hao, L. Wang, and F. Jiao, "The study and exploration of a new generation of photovoltaic energy storage system," *Energy Procedia,* vol. 12, pp. 986-993, 2011.

[14] M. Hosenuzzaman, N. A. Rahim, J. Selvaraj, M. Hasanuzzaman, A. B. M. A. Malek, and A. Nahar, "Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation," *Renewable and Sustainable Energy Reviews,* vol. 41, pp. 284-297, 2015.

[15] S. C. XC, "30kvw Solar Power Generation System Application And Operation," *Power Electron 2009,* pp. 42-4, 2009.

[16] A. Woyte, M. Richter, D. Moser, S. Mau, N. Reich, and U. Jahn, "Monitoring of photovoltaic systems: good practices and systematic analysis," in *Proc. 28th European Photovoltaic Solar Energy Conference*, 2013, pp. 3686-3694.

[17] B. Decker and U. Jahn, "Performance of 170 grid connected PV plants in northern Germany—analysis of yields and optimization potentials," *Solar Energy,* vol. 59, pp. 127-133, 1997.

[18] B. Marion, J. Adelstein, K. Boyle, H. Hayden, B. Hammond, T. Fletcher*, et al.*, "Performance parameters for grid-connected PV systems," in *Photovoltaic Specialists Conference, 2005. Conference Record of the Thirty-first IEEE*, 2005, pp. 1601-1606.

[19] L. Maturi, "Building skin as energy supply: Prototype development of a wooden prefabricated BiPV wall," University of Trento, 2013.

[20] J. Wong, Y. S. Lim, J. H. Tang, and E. Morris, "Grid-connected photovoltaic system in Malaysia: A review on voltage issues," *Renewable and Sustainable Energy Reviews,* vol. 29, pp. 535-545, 2014.

[21] B. P. Koirala, B. Sahan, and N. Henze, "Study on MPP mismatch losses in photovoltaic applications," *24th EUPVSEC,* pp. 3727-3733, 2009.

[22] C. S. Inc., "CS6P 235/240/245/250/255P," ed, 2012.

[23] S. Boy, "5000TL Multi-String–Operating Instructions, SMA," ed, 2005.

[24] A. Sasitharanuwat, W. Rakwichian, N. Ketjoy, and S. Yammen, "Performance evaluation of a 10kW p PV power system prototype for isolated building in Thailand," *Renewable energy,* vol. 32, pp. 1288-1300, 2007.

[25] E. Kymakis, S. Kalykakis, and T. M. Papazoglou, "Performance analysis of a grid connected photovoltaic park on the island of Crete," *Energy Conversion and Management,* vol. 50, pp. 433-438, 2009.

[26] S. Dubey, J. N. Sarvaiya, and B. Seshadri, "Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world–a review," *Energy Procedia,* vol. 33, pp. 311-321, 2013.

[27] G. Santana-Rodríguez, O. Vigil-Galan, D. Jimenez-Olarte, G. Contreras-Puente, B. Monroy, and A. Escamilla-Esquivel, "Evaluation of a grid-connected photovoltaic system and in-situ characterization of photovoltaic modules under the environmental conditions of Mexico City," *Revista mexicana de física,* vol. 59, pp. 88-94, 2013.

[28] T. Ma, H. Yang, and L. Lu, "Performance evaluation of a stand-alone photovoltaic system on an isolated island in Hong Kong," *Applied Energy,* vol. 112, pp. 663-672, 2013.

[29] G. M. Tina and A. D. Grasso, "Remote monitoring system for stand-alone photovoltaic power plants: The case study of a PV-powered outdoor refrigerator," *Energy Conversion and Management,* vol. 78, pp. 862-871, 2014.

[30] A. El Fathi, L. Nkhaili, A. Bennouna, and A. Outzourhit, "Performance parameters of a standalone PV plant," *Energy Conversion and Management,* vol. 86, pp. 490-495, 2014.

[31] Z. Glasnovic and J. Margeta, "Vision of total renewable electricity scenario," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 1873-1884, 2011.

[32] J. A. Duffie, W. A. Beckman, and W. Worek, "Solar engineering of thermal processes," ed: American Society of Mechanical Engineers, 1994.

[33] J. Kim, J. M. Guerrero, P. Rodriguez, R. Teodorescu, and K. Nam, "Mode adaptive droop control with virtual output impedances for an inverter-based flexible AC microgrid," *Power Electronics, IEEE Transactions on,* vol. 26, pp. 689-701, 2011.

[34] B. Panahandeh, J. Bard, A. Outzourhit, and D. Zejli, "Simulation of PV–wind-hybrid systems combined with hydrogen storage for rural electrification," *International journal of hydrogen energy,* vol. 36, pp. 4185-4197, 2011.

[35] A. Woyte, M. Richter, D. Moser, N. Reich, M. Green, S. Mau*, et al.*, "Analytical monitoring of grid-connected photovoltaic systems," *IEA-PVPS T13-03,* vol. 2014, 2014.

# APPENDIX

TABLE 7: Insolation, Ambient Temperature, Wind Velocity and Estimated Cell Temperature of Day 1

| Time | Insolation | Temperature | Wind Velocity | Cell Temperature |
|---|---|---|---|---|
| 00:00:00 | 0 | 26.24 | 0.51 | 26.24 |
| 00:15:00 | 0.01 | 26.14 | 0.79 | 26.14028225 |
| 00:30:00 | 0.09 | 26.15 | 0.41 | 26.15304565 |
| 00:45:00 | 0.12 | 25.87 | 0.55 | 25.87378354 |
| 01:00:00 | 0.12 | 25.8 | 0.58 | 25.80372897 |
| 01:15:00 | 0.11 | 25.76 | 0.55 | 25.76346824 |
| 01:30:00 | 0.13 | 25.6 | 0.42 | 25.60437636 |
| 01:45:00 | 0.11 | 25.64 | 0.18 | 25.64423208 |
| 02:00:00 | 0.01 | 25.53 | 0.18 | 25.53038473 |
| 02:15:00 | 0.01 | 25.42 | 0.1 | 25.42040397 |
| 02:30:00 | 0.07 | 25.45 | 0 | 25.45301632 |
| 02:45:00 | 0.01 | 25.36 | 0 | 25.3604309 |
| 03:00:00 | 0.14 | 25.38 | 0 | 25.38603264 |
| 03:15:00 | 0 | 25.35 | 0 | 25.35 |
| 03:30:00 | 0 | 25.32 | 0.01 | 25.32 |
| 03:45:00 | 0.17 | 25.31 | 0 | 25.31732535 |
| 04:00:00 | 0.01 | 25.46 | 0.02 | 25.46042523 |
| 04:15:00 | 0.07 | 25.43 | 0.1 | 25.4328278 |
| 04:30:00 | 0.15 | 25.32 | 0.05 | 25.32625504 |
| 04:45:00 | 0 | 25.34 | 0 | 25.34 |
| 05:00:00 | 0.02 | 25.28 | 0.01 | 25.2808561 |
| 05:15:00 | 0.04 | 25.19 | 0 | 25.19172361 |
| 05:30:00 | 0.34 | 25.2 | 0.28 | 25.21234609 |
| 05:45:00 | 0.01 | 25.18 | 0 | 25.1804309 |
| 06:00:00 | 0.01 | 25.14 | 0.01 | 25.14042805 |
| 06:15:00 | 0 | 24.9 | 0.08 | 24.9 |
| 06:30:00 | 0 | 24.8 | 0.01 | 24.8 |
| 06:45:00 | 0 | 24.74 | 0 | 24.74 |
| 07:00:00 | 0 | 24.7 | 0 | 24.7 |
| 07:15:00 | 0.58 | 24.62 | 0 | 24.64499236 |
| 07:30:00 | 7.26 | 24.51 | 0 | 24.82283542 |
| 07:45:00 | 21.09 | 24.65 | 0 | 25.55877396 |
| 08:00:00 | 49.01 | 25.01 | 0 | 27.12185451 |
| 08:15:00 | 81.88 | 25.56 | 0 | 29.08823194 |

| | | | | |
|---|---|---|---|---|
| 08:30:00 | 107.67 | 26.06 | 0 | 30.69953021 |
| 08:45:00 | 137.16 | 26.47 | 0 | 32.3802625 |
| 09:00:00 | 181.08 | 27.13 | 0.01 | 34.88111341 |
| 09:15:00 | 266.39 | 27.9 | 0.01 | 39.30280043 |
| 09:30:00 | 383.59 | 28.6 | 0.24 | 42.84913763 |
| 09:45:00 | 473.81 | 28.88 | 0.12 | 47.78426344 |
| 10:00:00 | 532.19 | 30.01 | 0.36 | 48.50372172 |
| 10:15:00 | 300.95 | 30.16 | 0.19 | 41.67007612 |
| 10:30:00 | 606.31 | 30.18 | 0.3 | 51.95172193 |
| 10:45:00 | 490.08 | 30.58 | 0.37 | 47.51931818 |
| 11:00:00 | 614.8 | 31.53 | 0.38 | 52.66715647 |
| 11:15:00 | 467.96 | 31.98 | 0.11 | 50.76682583 |
| 11:30:00 | 541.59 | 30.47 | 0.81 | 45.62406723 |
| 11:45:00 | 585.13 | 31.69 | 0.68 | 49.03867952 |
| 12:00:00 | 604.33 | 31.81 | 0.72 | 49.40509971 |
| 12:15:00 | 831.23 | 32.56 | 0.93 | 54.66983432 |
| 12:30:00 | 558.36 | 32.05 | 0.87 | 47.2777769 |
| 12:45:00 | 590.34 | 32.74 | 0.62 | 50.73852447 |
| 13:00:00 | 573.78 | 32.6 | 0.9 | 48.05271224 |
| 13:15:00 | 711.08 | 32.82 | 0.81 | 52.71651605 |
| 13:30:00 | 746.99 | 32.9 | 1.12 | 51.32824805 |
| 13:45:00 | 904 | 33.63 | 0.93 | 57.67543896 |
| 14:00:00 | 982.9 | 34.16 | 1.18 | 57.86528024 |
| 14:15:00 | 1104.31 | 35.64 | 0.91 | 65.25723526 |
| 14:30:00 | 1188.41 | 35.63 | 1.41 | 62.02634898 |
| 14:45:00 | 1164.73 | 36.79 | 0.78 | 69.80877581 |
| 15:00:00 | 1092.69 | 36.9 | 0.68 | 69.29746488 |
| 15:15:00 | 1112.52 | 36.92 | 0.95 | 66.27028316 |
| 15:30:00 | 1056.66 | 35.69 | 1.39 | 59.32240809 |
| 15:45:00 | 906.24 | 36.12 | 1.13 | 58.39193916 |
| 16:00:00 | 839.26 | 37.06 | 0.88 | 59.85240327 |
| 16:15:00 | 876.25 | 37.38 | 0.89 | 61.0773991 |
| 16:30:00 | 799 | 35.9 | 1.17 | 55.24220896 |
| 16:45:00 | 760.49 | 35.69 | 0.96 | 55.67153985 |
| 17:00:00 | 562.1 | 34.85 | 0.86 | 50.24473208 |
| 17:15:00 | 542.32 | 34.16 | 1.22 | 47.04716146 |
| 17:30:00 | 363.41 | 33.33 | 1.34 | 41.60082985 |
| 17:45:00 | 118.99 | 31.46 | 1.06 | 34.46428446 |
| 18:00:00 | 114.2 | 31.08 | 1.1 | 33.91898638 |
| 18:15:00 | 102.22 | 30.34 | 1.1 | 32.88116627 |

| | | | | |
|---|---|---|---|---|
| 18:30:00 | 113.99 | 29.7 | 1.58 | 32.09213998 |
| 18:45:00 | 83.32 | 28.75 | 1 | 30.90416917 |
| 19:00:00 | 41.4 | 27.73 | 0.86 | 28.86385858 |
| 19:15:00 | 14.48 | 27.37 | 0.38 | 27.86783023 |
| 19:30:00 | 3.32 | 27.28 | 0.5 | 27.38729479 |
| 19:45:00 | 0 | 27.21 | 0.32 | 27.21 |
| 20:00:00 | 0 | 27.23 | 0.49 | 27.23 |
| 20:15:00 | 0 | 27.1 | 0.11 | 27.1 |
| 20:30:00 | 0 | 26.91 | 0.18 | 26.91 |
| 20:45:00 | 0 | 26.67 | 0.01 | 26.67 |
| 21:00:00 | 0 | 26.65 | 0.06 | 26.65 |
| 21:15:00 | 0 | 26.61 | 0.07 | 26.61 |
| 21:30:00 | 0 | 26.67 | 0.41 | 26.67 |
| 21:45:00 | 0.01 | 26.55 | 0.1 | 26.55040397 |
| 22:00:00 | 0 | 26.58 | 0.04 | 26.58 |
| 22:15:00 | 0 | 26.59 | 0 | 26.59 |
| 22:30:00 | 0 | 26.39 | 0 | 26.39 |
| 22:45:00 | 0.01 | 26.25 | 0 | 26.2504309 |
| 23:00:00 | 0 | 26.01 | 0 | 26.01 |
| 23:15:00 | 0 | 25.91 | 0 | 25.91 |
| 23:30:00 | 0 | 25.9 | 0 | 25.9 |
| 23:45:00 | 0 | 25.89 | 0 | 25.89 |

TABLE 8: Insolation, Ambient Temperature, Wind Velocity and Estimated Cell Temperature of Day 2

| Time | Insolation | Temperature | Wind Velocity | Cell Temperature |
|---|---|---|---|---|
| 00:00:00 | 0 | 24.87 | 0 | 24.87 |
| 00:15:00 | 0 | 25.12 | 0 | 25.12 |
| 00:30:00 | 0 | 25.04 | 0.08 | 25.04 |
| 00:45:00 | 0 | 24.92 | 0.3 | 24.92 |
| 01:00:00 | 0 | 24.72 | 0.08 | 24.72 |
| 01:15:00 | 0 | 24.7 | 0.02 | 24.7 |
| 01:30:00 | 0 | 24.62 | 0.15 | 24.62 |
| 01:45:00 | 0 | 24.62 | 0.04 | 24.62 |
| 02:00:00 | 0 | 24.64 | 0.01 | 24.64 |
| 02:15:00 | 0 | 24.6 | 0.24 | 24.6 |
| 02:30:00 | 0 | 24.5 | 0.48 | 24.5 |
| 02:45:00 | 0 | 24.44 | 0.7 | 24.44 |
| 03:00:00 | 0 | 24.34 | 0.42 | 24.34 |

| | | | | |
|---|---|---|---|---|
| 03:15:00 | 0 | 24.25 | 0.41 | 24.25 |
| 03:30:00 | 0 | 24.2 | 0.8 | 24.2 |
| 03:45:00 | 0 | 24.08 | 0.97 | 24.08 |
| 04:00:00 | 0 | 23.87 | 0.99 | 23.87 |
| 04:15:00 | 0 | 23.82 | 0.91 | 23.82 |
| 04:30:00 | 0 | 23.89 | 0.63 | 23.89 |
| 04:45:00 | 0 | 23.91 | 0.8 | 23.91 |
| 05:00:00 | 0 | 23.95 | 0.71 | 23.95 |
| 05:15:00 | 0 | 23.78 | 0 | 23.78 |
| 05:30:00 | 0 | 23.48 | 0 | 23.48 |
| 05:45:00 | 0 | 23.13 | 0.33 | 23.13 |
| 06:00:00 | 0 | 23.09 | 0.88 | 23.09 |
| 06:15:00 | 0 | 23.06 | 0.53 | 23.06 |
| 06:30:00 | 0 | 23.02 | 0.43 | 23.02 |
| 06:45:00 | 0 | 23.18 | 0.07 | 23.18 |
| 07:00:00 | 0 | 23.16 | 0.17 | 23.16 |
| 07:15:00 | 0.88 | 22.93 | 0.03 | 22.96717593 |
| 07:30:00 | 9.51 | 22.89 | 0.54 | 23.1913151 |
| 07:45:00 | 25.08 | 23.05 | 0 | 24.13070417 |
| 08:00:00 | 43.35 | 23.05 | 0.01 | 24.90559292 |
| 08:15:00 | 90.74 | 23.28 | 0 | 27.19001181 |
| 08:30:00 | 144.14 | 23.76 | 0.51 | 28.39509898 |
| 08:45:00 | 189.94 | 24.56 | 0.63 | 30.32377983 |
| 09:00:00 | 288.13 | 25.35 | 0.99 | 32.82927815 |
| 09:15:00 | 358.88 | 26.12 | 1.34 | 34.28773181 |
| 09:30:00 | 514.04 | 26.65 | 1.28 | 38.60150704 |
| 09:45:00 | 494.98 | 27.82 | 1.72 | 37.75578837 |
| 10:00:00 | 521.62 | 28.24 | 2 | 37.87289315 |
| 10:15:00 | 639.22 | 28.47 | 1.98 | 40.34248593 |
| 10:30:00 | 611.3 | 28.88 | 1.6 | 41.62568716 |
| 10:45:00 | 754.55 | 29.77 | 1.6 | 45.50246892 |
| 11:00:00 | 744.6 | 30.47 | 1.91 | 44.58364553 |
| 11:15:00 | 680.26 | 30.59 | 1.71 | 44.28747307 |
| 11:30:00 | 829.07 | 30.87 | 1.65 | 47.88183647 |
| 11:45:00 | 980.64 | 31.45 | 1.64 | 51.63601115 |
| 12:00:00 | 1065.42 | 32.39 | 1.81 | 53.19479324 |
| 12:15:00 | 1107.01 | 33.26 | 0.7 | 65.78366027 |
| 12:30:00 | 1134.21 | 35.1 | 0.96 | 64.90086827 |
| 12:45:00 | 1144.06 | 35.83 | 0.98 | 65.64725596 |
| 13:00:00 | 1129.49 | 36.18 | 0.76 | 68.48312246 |

| | | | | |
|---|---|---|---|---|
| 13:15:00 | 1171.83 | 36.84 | 0.87 | 68.79853178 |
| 13:30:00 | 1249.25 | 37.44 | 1.31 | 66.1751581 |
| 13:45:00 | 1218.72 | 36.31 | 0.9 | 69.13186458 |
| 14:00:00 | 1213.4 | 38.34 | 1.2 | 67.38763503 |
| 14:15:00 | 1215.33 | 38.14 | 1.33 | 65.89737136 |
| 14:30:00 | 1047.71 | 40.09 | 1.2 | 65.17117496 |
| 14:45:00 | 1145.2 | 39.57 | 0.74 | 72.61485677 |
| 15:00:00 | 1010.54 | 40.29 | 0.87 | 67.84977804 |
| 15:15:00 | 1114.82 | 39.43 | 0.98 | 68.48518355 |
| 15:30:00 | 987.57 | 39.25 | 1.3 | 62.0471423 |
| 15:45:00 | 1075.78 | 38.79 | 1.41 | 62.6846696 |
| 16:00:00 | 442.38 | 38.82 | 1.9 | 47.22982813 |
| 16:15:00 | 314.49 | 35.58 | 1.82 | 41.70264825 |
| 16:30:00 | 160.83 | 33.49 | 1.76 | 36.67874664 |
| 16:45:00 | 199.16 | 32.42 | 1.87 | 36.23981887 |
| 17:00:00 | 494.31 | 31.72 | 1.46 | 42.51389622 |
| 17:15:00 | 557.65 | 32.49 | 1.64 | 43.96896182 |
| 17:30:00 | 421.29 | 33.5 | 1.41 | 42.85747584 |
| 17:45:00 | 189.68 | 33.72 | 1.36 | 38.00672931 |
| 18:00:00 | 127.04 | 32.57 | 1.28 | 35.52369904 |
| 18:15:00 | 154.76 | 31.99 | 1.25 | 35.62744621 |
| 18:30:00 | 144.07 | 31.56 | 1.31 | 34.87388772 |
| 18:45:00 | 95.61 | 31.9 | 1.56 | 33.91953993 |
| 19:00:00 | 58.28 | 31.25 | 1.09 | 32.70442165 |
| 19:15:00 | 16.64 | 30.54 | 0.99 | 30.9719411 |
| 19:30:00 | 2.57 | 29.79 | 0.45 | 29.87518616 |
| 19:45:00 | 0 | 29.26 | 0.74 | 29.26 |
| 20:00:00 | 0 | 28.81 | 0.73 | 28.81 |
| 20:15:00 | 0 | 28.51 | 0.5 | 28.51 |
| 20:30:00 | 0 | 28.29 | 0.22 | 28.29 |
| 20:45:00 | 0 | 28.02 | 0.13 | 28.02 |
| 21:00:00 | 0 | 27.88 | 0.14 | 27.88 |
| 21:15:00 | 0 | 27.65 | 0.02 | 27.65 |
| 21:30:00 | 0 | 27.53 | 0 | 27.53 |
| 21:45:00 | 0 | 27.17 | 0 | 27.17 |
| 22:00:00 | 0 | 26.94 | 0 | 26.94 |
| 22:15:00 | 0 | 26.83 | 0 | 26.83 |
| 22:30:00 | 0 | 26.24 | 0 | 26.24 |
| 22:45:00 | 0 | 25.96 | 0 | 25.96 |
| 23:00:00 | 0 | 25.79 | 0 | 25.79 |

| | | | | |
|---|---|---|---|---|
| 23:15:00 | 0 | 25.54 | 0 | 25.54 |
| 23:30:00 | 0 | 25.24 | 0 | 25.24 |
| 23:45:00 | 0 | 25.01 | 0 | 25.01 |

TABLE 9: Insolation, Ambient Temperature, Wind Velocity and Estimated Cell Temperature of Day 3

| Time | Insolation | Temperature | Wind Velocity | Cell Temperature |
|---|---|---|---|---|
| 00:00:00 | 0 | 24.64 | 0.01 | 24.64 |
| 00:15:00 | 0 | 26.02 | 0 | 26.02 |
| 00:30:00 | 0 | 25.94 | 0 | 25.94 |
| 00:45:00 | 0 | 25.78 | 0 | 25.78 |
| 01:00:00 | 0 | 25.63 | 0 | 25.63 |
| 01:15:00 | 0 | 25.5 | 0 | 25.5 |
| 01:30:00 | 0 | 25.46 | 0 | 25.46 |
| 01:45:00 | 0.02 | 25.42 | 0 | 25.42086181 |
| 02:00:00 | 0 | 25.34 | 0 | 25.34 |
| 02:15:00 | 0 | 25.22 | 0 | 25.22 |
| 02:30:00 | 0 | 25.13 | 0 | 25.13 |
| 02:45:00 | 0 | 25.1 | 0 | 25.1 |
| 03:00:00 | 0 | 25.04 | 0 | 25.04 |
| 03:15:00 | 0 | 24.96 | 0 | 24.96 |
| 03:30:00 | 0 | 25 | 0 | 25 |
| 03:45:00 | 0 | 24.95 | 0.05 | 24.95 |
| 04:00:00 | 0 | 24.86 | 0 | 24.86 |
| 04:15:00 | 0 | 24.83 | 0 | 24.83 |
| 04:30:00 | 0.01 | 24.8 | 0 | 24.8004309 |
| 04:45:00 | 0 | 24.8 | 0.04 | 24.8 |
| 05:00:00 | 0 | 24.8 | 0 | 24.8 |
| 05:15:00 | 0 | 24.79 | 0.29 | 24.79 |
| 05:30:00 | 0 | 24.69 | 0.37 | 24.69 |
| 05:45:00 | 0 | 24.43 | 0.68 | 24.43 |
| 06:00:00 | 0 | 24.21 | 0.78 | 24.21 |
| 06:15:00 | 0 | 23.92 | 0.6 | 23.92 |
| 06:30:00 | 0 | 23.53 | 0.57 | 23.53 |
| 06:45:00 | 0 | 23.23 | 0.05 | 23.23 |
| 07:00:00 | 0 | 23.02 | 0.03 | 23.02 |
| 07:15:00 | 0.7 | 22.88 | 0 | 22.91016319 |
| 07:30:00 | 7.48 | 22.74 | 0 | 23.06231528 |
| 07:45:00 | 28.51 | 22.57 | 0.09 | 23.72896587 |

| | | | | |
|---|---|---|---|---|
| 08:00:00 | 63.26 | 22.7 | 0.05 | 25.33795901 |
| 08:15:00 | 67.16 | 23.17 | 0 | 26.06394306 |
| 08:30:00 | 105.75 | 23.6 | 0 | 28.15679688 |
| 08:45:00 | 131.96 | 24.13 | 0 | 29.81619306 |
| 09:00:00 | 237.9 | 24.69 | 0.01 | 34.87328849 |
| 09:15:00 | 311.66 | 25.35 | 0.49 | 35.47275073 |
| 09:30:00 | 394.06 | 25.61 | 0.66 | 37.40177421 |
| 09:45:00 | 472.63 | 26.2 | 0.75 | 39.77717199 |
| 10:00:00 | 548.2 | 26.93 | 0.48 | 44.82552294 |
| 10:15:00 | 626.05 | 27.66 | 0.65 | 46.48093144 |
| 10:30:00 | 694.55 | 28.78 | 0.38 | 52.6590046 |
| 10:45:00 | 763.14 | 29.73 | 0.46 | 54.89626116 |
| 11:00:00 | 827.86 | 30.37 | 0.33 | 59.60993226 |
| 11:15:00 | 885.09 | 30.92 | 0.62 | 57.90498157 |
| 11:30:00 | 930.59 | 31.96 | 0.3 | 65.37615133 |
| 11:45:00 | 975.98 | 32.6 | 0.48 | 64.46003735 |
| 12:00:00 | 1019.85 | 32.6 | 0.69 | 62.69973958 |
| 12:15:00 | 1045.77 | 33.53 | 0.75 | 63.57167986 |
| 12:30:00 | 1079.42 | 33.39 | 0.98 | 61.5225651 |
| 12:45:00 | 1114.28 | 33.98 | 0.7 | 66.71725095 |
| 13:00:00 | 1130.52 | 34.4 | 0.77 | 66.59014593 |
| 13:15:00 | 1146.45 | 35.31 | 0.73 | 68.5392706 |
| 13:30:00 | 1154.35 | 36.16 | 0.68 | 70.3856391 |
| 13:45:00 | 1152.96 | 36.33 | 0.56 | 72.50575243 |
| 14:00:00 | 1147.94 | 36.9 | 0.62 | 71.89885859 |
| 14:15:00 | 1136.62 | 37.44 | 0.91 | 67.92377896 |
| 14:30:00 | 1120.15 | 37.77 | 0.99 | 66.8468522 |
| 14:45:00 | 1093.22 | 36.93 | 0.97 | 65.53758308 |
| 15:00:00 | 1050.67 | 37.33 | 0.89 | 65.74443231 |
| 15:15:00 | 1003.12 | 36.67 | 1.13 | 61.32288181 |
| 15:30:00 | 969.09 | 37.34 | 0.99 | 62.49563692 |
| 15:45:00 | 911.8 | 37.14 | 0.95 | 61.19492772 |
| 16:00:00 | 844.41 | 36.38 | 1.16 | 56.89834293 |
| 16:15:00 | 784.74 | 37.2 | 0.78 | 59.44648986 |
| 16:30:00 | 713.25 | 37.19 | 0.87 | 56.64198774 |
| 16:45:00 | 644.71 | 38.43 | 0.84 | 56.23816217 |
| 17:00:00 | 563.56 | 36.63 | 0.93 | 51.62009688 |
| 17:15:00 | 484.87 | 35.67 | 0.75 | 49.59878866 |
| 17:30:00 | 393.99 | 36.22 | 0.76 | 47.48801231 |
| 17:45:00 | 329.6 | 33.7 | 1.62 | 40.52815171 |

| | | | | |
|---|---|---|---|---|
| 18:00:00 | 258.7 | 33.19 | 1.68 | 38.44823343 |
| 18:15:00 | 203.28 | 32.02 | 1.74 | 36.07527392 |
| 18:30:00 | 138.52 | 31.69 | 1.28 | 34.91061076 |
| 18:45:00 | 84.67 | 30.92 | 1.7 | 32.63021273 |
| 19:00:00 | 46.97 | 30.21 | 1.52 | 31.21527335 |
| 19:15:00 | 20.08 | 29.42 | 1.72 | 29.82306806 |
| 19:30:00 | 4.25 | 29.01 | 1.11 | 29.11524924 |
| 19:45:00 | 0.25 | 28.63 | 0.87 | 28.63681808 |
| 20:00:00 | 0 | 28.35 | 0.85 | 28.35 |
| 20:15:00 | 0.01 | 28.12 | 0.5 | 28.12032318 |
| 20:30:00 | 0.02 | 27.96 | 0.48 | 27.96065288 |
| 20:45:00 | 0.04 | 27.75 | 0.22 | 27.75150315 |
| 21:00:00 | 0 | 27.57 | 0.12 | 27.57 |
| 21:15:00 | 0 | 27.42 | 0.06 | 27.42 |
| 21:30:00 | 0.01 | 27.26 | 0 | 27.2604309 |
| 21:45:00 | 0 | 26.85 | 0 | 26.85 |
| 22:00:00 | 0 | 26.14 | 0 | 26.14 |
| 22:15:00 | 0 | 25.75 | 0 | 25.75 |
| 22:30:00 | 0 | 25.56 | 0 | 25.56 |
| 22:45:00 | 0.01 | 25.33 | 0 | 25.3304309 |
| 23:00:00 | 0.01 | 25.13 | 0 | 25.1304309 |
| 23:15:00 | 0.19 | 25 | 0 | 25.00818715 |
| 23:30:00 | 0.05 | 24.91 | 0 | 24.91215451 |
| 23:45:00 | 0.1 | 24.78 | 0.05 | 24.78417003 |

TABLE 10 Power Yield of Day 1, Day 2 and Day 3

| Day 1 | |
|---|---|
| **Time** | **Power** |
| 00:00:00 | 0 |
| 00:05:00 | 0 |
| 00:10:00 | 0 |
| 00:15:00 | 0 |
| 00:20:00 | 0 |
| 00:25:00 | 0 |
| 00:30:00 | 0 |
| 00:35:00 | 0 |
| 00:40:00 | 0 |
| 00:45:00 | 0 |
| 00:50:00 | 0 |

| Day 2 | |
|---|---|
| **Time** | **Power** |
| 00:00:00 | 0 |
| 00:15:00 | 0 |
| 00:30:00 | 0 |
| 00:45:00 | 0 |
| 01:00:00 | 0 |
| 01:15:00 | 0 |
| 01:30:00 | 0 |
| 01:45:00 | 0 |
| 02:00:00 | 0 |
| 02:15:00 | 0 |
| 02:30:00 | 0 |

| Day 3 | |
|---|---|
| **Time** | **Power** |
| 00:00:00 | 0 |
| 00:05:00 | 0 |
| 00:10:00 | 0 |
| 00:15:00 | 0 |
| 00:20:00 | 0 |
| 00:25:00 | 0 |
| 00:30:00 | 0 |
| 00:35:00 | 0 |
| 00:40:00 | 0 |
| 00:45:00 | 0 |
| 00:50:00 | 0 |

| | |
|---|---|
| 00:55:00 | 0 |
| 01:00:00 | 0 |
| 01:05:00 | 0 |
| 01:10:00 | 0 |
| 01:15:00 | 0 |
| 01:20:00 | 0 |
| 01:25:00 | 0 |
| 01:30:00 | 0 |
| 01:35:00 | 0 |
| 01:40:00 | 0 |
| 01:45:00 | 0 |
| 01:50:00 | 0 |
| 01:55:00 | 0 |
| 02:00:00 | 0 |
| 02:05:00 | 0 |
| 02:10:00 | 0 |
| 02:15:00 | 0 |
| 02:20:00 | 0 |
| 02:25:00 | 0 |
| 02:30:00 | 0 |
| 02:35:00 | 0 |
| 02:40:00 | 0 |
| 02:45:00 | 0 |
| 02:50:00 | 0 |
| 02:55:00 | 0 |
| 03:00:00 | 0 |
| 03:05:00 | 0 |
| 03:10:00 | 0 |
| 03:15:00 | 0 |
| 03:20:00 | 0 |
| 03:25:00 | 0 |
| 03:30:00 | 0 |
| 03:35:00 | 0 |
| 03:40:00 | 0 |
| 03:45:00 | 0 |
| 03:50:00 | 0 |
| 03:55:00 | 0 |
| 04:00:00 | 0 |
| 04:05:00 | 0 |
| 04:10:00 | 0 |
| 04:15:00 | 0 |

| | |
|---|---|
| 02:45:00 | 0 |
| 03:00:00 | 0 |
| 03:15:00 | 0 |
| 03:30:00 | 0 |
| 03:45:00 | 0 |
| 04:00:00 | 0 |
| 04:15:00 | 0 |
| 04:30:00 | 0 |
| 04:45:00 | 0 |
| 05:00:00 | 0 |
| 05:15:00 | 0 |
| 05:30:00 | 0 |
| 05:45:00 | 0 |
| 06:00:00 | 0 |
| 06:15:00 | 0 |
| 06:30:00 | 0 |
| 06:45:00 | 0 |
| 07:00:00 | 0 |
| 07:15:00 | 0 |
| 07:30:00 | 0 |
| 07:45:00 | 0 |
| 08:00:00 | 0 |
| 08:15:00 | 0 |
| 08:30:00 | 0 |
| 08:45:00 | 0 |
| 09:00:00 | 0 |
| 09:15:00 | 0 |
| 09:30:00 | 0 |
| 09:45:00 | 0 |
| 10:00:00 | 0 |
| 10:15:00 | 0 |
| 10:30:00 | 0 |
| 10:45:00 | 0 |
| 11:00:00 | 0 |
| 11:15:00 | 0 |
| 11:30:00 | 0 |
| 11:45:00 | 0 |
| 12:00:00 | 0 |
| 12:15:00 | 0 |
| 12:30:00 | 0 |
| 12:45:00 | 0 |

| | |
|---|---|
| 00:55:00 | 0 |
| 01:00:00 | 0 |
| 01:05:00 | 0 |
| 01:10:00 | 0 |
| 01:15:00 | 0 |
| 01:20:00 | 0 |
| 01:25:00 | 0 |
| 01:30:00 | 0 |
| 01:35:00 | 0 |
| 01:40:00 | 0 |
| 01:45:00 | 0 |
| 01:50:00 | 0 |
| 01:55:00 | 0 |
| 02:00:00 | 0 |
| 02:05:00 | 0 |
| 02:10:00 | 0 |
| 02:15:00 | 0 |
| 02:20:00 | 0 |
| 02:25:00 | 0 |
| 02:30:00 | 0 |
| 02:35:00 | 0 |
| 02:40:00 | 0 |
| 02:45:00 | 0 |
| 02:50:00 | 0 |
| 02:55:00 | 0 |
| 03:00:00 | 0 |
| 03:05:00 | 0 |
| 03:10:00 | 0 |
| 03:15:00 | 0 |
| 03:20:00 | 0 |
| 03:25:00 | 0 |
| 03:30:00 | 0 |
| 03:35:00 | 0 |
| 03:40:00 | 0 |
| 03:45:00 | 0 |
| 03:50:00 | 0 |
| 03:55:00 | 0 |
| 04:00:00 | 0 |
| 04:05:00 | 0 |
| 04:10:00 | 0 |
| 04:15:00 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 04:20:00 | 0 | 13:00:00 | 0 | 04:20:00 | 0 |
| 04:25:00 | 0 | 13:15:00 | 0 | 04:25:00 | 0 |
| 04:30:00 | 0 | 13:30:00 | 0 | 04:30:00 | 0 |
| 04:35:00 | 0 | 13:45:00 | 0 | 04:35:00 | 0 |
| 04:40:00 | 0 | 14:00:00 | 0 | 04:40:00 | 0 |
| 04:45:00 | 0 | 14:15:00 | 0 | 04:45:00 | 0 |
| 04:50:00 | 0 | 14:30:00 | 0 | 04:50:00 | 0 |
| 04:55:00 | 0 | 14:45:00 | 0 | 04:55:00 | 0 |
| 05:00:00 | 0 | 15:00:00 | 0 | 05:00:00 | 0 |
| 05:05:00 | 0 | 15:15:00 | 0 | 05:05:00 | 0 |
| 05:10:00 | 0 | 15:30:00 | 0 | 05:10:00 | 0 |
| 05:15:00 | 0 | 15:45:00 | 0 | 05:15:00 | 0 |
| 05:20:00 | 0 | 16:00:00 | 0 | 05:20:00 | 0 |
| 05:25:00 | 0 | 16:15:00 | 0 | 05:25:00 | 0 |
| 05:30:00 | 0 | 16:30:00 | 0 | 05:30:00 | 0 |
| 05:35:00 | 0 | 16:45:00 | 0 | 05:35:00 | 0 |
| 05:40:00 | 0 | 17:00:00 | 0 | 05:40:00 | 0 |
| 05:45:00 | 0 | 17:15:00 | 0 | 05:45:00 | 0 |
| 05:50:00 | 0 | 17:30:00 | 0 | 05:50:00 | 0 |
| 05:55:00 | 0 | 17:45:00 | 0 | 05:55:00 | 0 |
| 06:00:00 | 0 | 18:00:00 | 0 | 06:00:00 | 0 |
| 06:05:00 | 0 | 18:15:00 | 0 | 06:05:00 | 0 |
| 06:10:00 | 0 | 18:30:00 | 0 | 06:10:00 | 0 |
| 06:15:00 | 0 | 18:45:00 | 0 | 06:15:00 | 0 |
| 06:20:00 | 0 | 19:00:00 | 0 | 06:20:00 | 0 |
| 06:25:00 | 0 | 19:15:00 | 0 | 06:25:00 | 0 |
| 06:30:00 | 0 | 19:30:00 | 0 | 06:30:00 | 0 |
| 06:35:00 | 0 | 19:45:00 | 0 | 06:35:00 | 0 |
| 06:40:00 | 0 | 20:00:00 | 0 | 06:40:00 | 0 |
| 06:45:00 | 0 | 20:15:00 | 0 | 06:45:00 | 0 |
| 06:50:00 | 0 | 20:30:00 | 0 | 06:50:00 | 0 |
| 06:55:00 | 0 | 20:45:00 | 0 | 06:55:00 | 0 |
| 07:00:00 | 0 | 21:00:00 | 0 | 07:00:00 | 0 |
| 07:05:00 | 0 | 21:15:00 | 0 | 07:05:00 | 0 |
| 07:10:00 | 0 | 21:30:00 | 0 | 07:10:00 | 0 |
| 07:15:00 | 0 | 21:45:00 | 0 | 07:15:00 | 0 |
| 07:20:00 | 0 | 22:00:00 | 0 | 07:20:00 | 0 |
| 07:25:00 | 0 | 22:15:00 | 0 | 07:25:00 | 0 |
| 07:30:00 | 0 | 22:30:00 | 0 | 07:30:00 | 0 |
| 07:35:00 | 0 | 22:45:00 | 0 | 07:35:00 | 0 |
| 07:40:00 | 0 | 23:00:00 | 0.036 | 07:40:00 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 07:45:00 | 0.024 | 23:15:00 | 0.06 | 07:45:00 | 0 |
| 07:50:00 | 0.048 | 23:30:00 | 0.06 | 07:50:00 | 0.048 |
| 07:55:00 | 0.084 | 23:45:00 | 0.096 | 07:55:00 | 0.084 |
| 08:00:00 | 0.124 | 08:00:00 | 0.108 | 08:00:00 | 0.154 |
| 08:05:00 | 0.138 | 08:05:00 | 0.156 | 08:05:00 | 0.204 |
| 08:10:00 | 0.204 | 08:10:00 | 0.228 | 08:10:00 | 0.276 |
| 08:15:00 | 0.276 | 08:15:00 | 0.12 | 08:15:00 | 0.324 |
| 08:20:00 | 0.294 | 08:20:00 | 0.132 | 08:20:00 | 0.324 |
| 08:25:00 | 0.305 | 08:25:00 | 0.132 | 08:25:00 | 0.252 |
| 08:30:00 | 0.342 | 08:30:00 | 0.132 | 08:30:00 | 0.288 |
| 08:35:00 | 0.384 | 08:35:00 | 0.12 | 08:35:00 | 0.54 |
| 08:40:00 | 0.42 | 08:40:00 | 0.12 | 08:40:00 | 0.636 |
| 08:45:00 | 0.468 | 08:45:00 | 0.12 | 08:45:00 | 0.732 |
| 08:50:00 | 0.528 | 08:50:00 | 0.12 | 08:50:00 | 0.828 |
| 08:55:00 | 0.528 | 08:55:00 | 0.108 | 08:55:00 | 0.924 |
| 09:00:00 | 0.48 | 09:00:00 | 0.108 | 09:00:00 | 1.032 |
| 09:05:00 | 0.48 | 09:05:00 | 0.108 | 09:05:00 | 1.14 |
| 09:10:00 | 0.564 | 09:10:00 | 0.108 | 09:10:00 | 1.224 |
| 09:15:00 | 0.768 | 09:15:00 | 0.108 | 09:15:00 | 1.308 |
| 09:20:00 | 0.828 | 09:20:00 | 0.108 | 09:20:00 | 1.428 |
| 09:25:00 | 0.756 | 09:25:00 | 0.372 | 09:25:00 | 1.51 |
| 09:30:00 | 0.756 | 09:30:00 | 0.468 | 09:30:00 | 1.584 |
| 09:35:00 | 0.756 | 09:35:00 | 0.48 | 09:35:00 | 1.716 |
| 09:40:00 | 0.756 | 09:40:00 | 0.48 | 09:40:00 | 1.8 |
| 09:45:00 | 0.744 | 09:45:00 | 0.48 | 09:45:00 | 1.92 |
| 09:50:00 | 0.744 | 09:50:00 | 0.48 | 09:50:00 | 2.016 |
| 09:55:00 | 0.732 | 09:55:00 | 0.48 | 09:55:00 | 2.088 |
| 10:00:00 | 0.72 | 10:00:00 | 0.48 | 10:00:00 | 2.184 |
| 10:05:00 | 0.732 | 10:05:00 | 0.48 | 10:05:00 | 2.352 |
| 10:10:00 | 0.708 | 10:10:00 | 0.48 | 10:10:00 | 2.352 |
| 10:15:00 | 0.72 | 10:15:00 | 0.468 | 10:15:00 | 2.448 |
| 10:20:00 | 0.713 | 10:20:00 | 0.48 | 10:20:00 | 2.532 |
| 10:25:00 | 0.702 | 10:25:00 | 0.492 | 10:25:00 | 2.604 |
| 10:30:00 | 0.684 | 10:30:00 | 0.48 | 10:30:00 | 2.664 |
| 10:35:00 | 0.696 | 10:35:00 | 0.48 | 10:35:00 | 2.724 |
| 10:40:00 | 0.684 | 10:40:00 | 0.48 | 10:40:00 | 2.796 |
| 10:45:00 | 0.684 | 10:45:00 | 0.492 | 10:45:00 | 2.844 |
| 10:50:00 | 0.684 | 10:50:00 | 0.48 | 10:50:00 | 2.928 |
| 10:55:00 | 0.672 | 10:55:00 | 0.492 | 10:55:00 | 2.97 |
| 11:00:00 | 0.672 | 11:00:00 | 0.48 | 11:00:00 | 2.88 |
| 11:05:00 | 0.672 | 11:05:00 | 0.48 | 11:05:00 | 2.748 |

| | | | | | |
|---|---|---|---|---|---|
| 11:10:00 | 0.672 | 11:10:00 | 0.492 | 11:10:00 | 2.604 |
| 11:15:00 | 0.672 | 11:15:00 | 0.468 | 11:15:00 | 2.46 |
| 11:20:00 | 0.66 | 11:20:00 | 0.492 | 11:20:00 | 2.316 |
| 11:25:00 | 0.66 | 11:25:00 | 0.48 | 11:25:00 | 2.208 |
| 11:30:00 | 0.66 | 11:30:00 | 0.48 | 11:30:00 | 2.1 |
| 11:35:00 | 0.66 | 11:35:00 | 0.48 | 11:35:00 | 1.992 |
| 11:40:00 | 0.66 | 11:40:00 | 0.48 | 11:40:00 | 1.884 |
| 11:45:00 | 0.648 | 11:45:00 | 0.492 | 11:45:00 | 1.848 |
| 11:50:00 | 0.648 | 11:50:00 | 0.48 | 11:50:00 | 1.716 |
| 11:55:00 | 0.648 | 11:55:00 | 0.492 | 11:55:00 | 1.656 |
| 12:00:00 | 0.648 | 12:00:00 | 0.492 | 12:00:00 | 1.584 |
| 12:05:00 | 0.648 | 12:05:00 | 0.48 | 12:05:00 | 1.524 |
| 12:10:00 | 0.648 | 12:10:00 | 0.492 | 12:10:00 | 1.464 |
| 12:15:00 | 0.636 | 12:15:00 | 0.504 | 12:15:00 | 1.416 |
| 12:20:00 | 0.648 | 12:20:00 | 0.492 | 12:20:00 | 1.368 |
| 12:25:00 | 0.636 | 12:25:00 | 0.492 | 12:25:00 | 1.32 |
| 12:30:00 | 0.636 | 12:30:00 | 0.504 | 12:30:00 | 1.284 |
| 12:35:00 | 0.624 | 12:35:00 | 0.492 | 12:35:00 | 1.248 |
| 12:40:00 | 0.636 | 12:40:00 | 0.492 | 12:40:00 | 1.224 |
| 12:45:00 | 0.624 | 12:45:00 | 0.492 | 12:45:00 | 1.128 |
| 12:50:00 | 0.63 | 12:50:00 | 0.492 | 12:50:00 | 0.564 |
| 12:55:00 | 0.63 | 12:55:00 | 0.504 | 12:55:00 | 0.492 |
| 13:00:00 | 0.624 | 13:00:00 | 0.492 | 13:00:00 | 0.504 |
| 13:05:00 | 0.624 | 13:05:00 | 0.492 | 13:05:00 | 0.528 |
| 13:10:00 | 0.612 | 13:10:00 | 0.504 | 13:10:00 | 0.528 |
| 13:15:00 | 0.624 | 13:15:00 | 0.492 | 13:15:00 | 0.54 |
| 13:20:00 | 0.624 | 13:20:00 | 0.504 | 13:20:00 | 0.552 |
| 13:25:00 | 0.624 | 13:25:00 | 0.504 | 13:25:00 | 0.552 |
| 13:30:00 | 0.624 | 13:30:00 | 0.504 | 13:30:00 | 0.564 |
| 13:35:00 | 0.612 | 13:35:00 | 0.504 | 13:35:00 | 0.564 |
| 13:40:00 | 0.624 | 13:40:00 | 0.504 | 13:40:00 | 0.564 |
| 13:45:00 | 0.612 | 13:45:00 | 0.492 | 13:45:00 | 0.576 |
| 13:50:00 | 0.624 | 13:50:00 | 0.504 | 13:50:00 | 0.564 |
| 13:55:00 | 0.624 | 13:55:00 | 0.504 | 13:55:00 | 0.588 |
| 14:00:00 | 0.612 | 14:00:00 | 0.492 | 14:00:00 | 0.588 |
| 14:05:00 | 0.624 | 14:05:00 | 0.504 | 14:05:00 | 0.582 |
| 14:10:00 | 0.624 | 14:10:00 | 0.504 | 14:10:00 | 0.576 |
| 14:15:00 | 0.612 | 14:15:00 | 0.516 | 14:15:00 | 0.588 |
| 14:20:00 | 0.612 | 14:20:00 | 0.516 | 14:20:00 | 0.576 |
| 14:25:00 | 0.612 | 14:25:00 | 0.516 | 14:25:00 | 0.588 |
| 14:30:00 | 0.624 | 14:30:00 | 0.504 | 14:30:00 | 0.588 |

| | | | | | |
|---|---|---|---|---|---|
| 14:35:00 | 0.624 | 14:35:00 | 0.516 | 14:35:00 | 0.582 |
| 14:40:00 | 0.612 | 14:40:00 | 0.528 | 14:40:00 | 0.588 |
| 14:45:00 | 0.618 | 14:45:00 | 0.504 | 14:45:00 | 0.576 |
| 14:50:00 | 0.612 | 14:50:00 | 0.516 | 14:50:00 | 0.588 |
| 14:55:00 | 0.624 | 14:55:00 | 0.516 | 14:55:00 | 0.588 |
| 15:00:00 | 0.6 | 15:00:00 | 0.504 | 15:00:00 | 0.588 |
| 15:05:00 | 0.612 | 15:05:00 | 0.516 | 15:05:00 | 0.588 |
| 15:10:00 | 0.624 | 15:10:00 | 0.516 | 15:10:00 | 0.588 |
| 15:15:00 | 0.624 | 15:15:00 | 0.516 | 15:15:00 | 0.588 |
| 15:20:00 | 0.612 | 15:20:00 | 0.504 | 15:20:00 | 0.588 |
| 15:25:00 | 0.624 | 15:25:00 | 0.516 | 15:25:00 | 0.588 |
| 15:30:00 | 0.624 | 15:30:00 | 0.516 | 15:30:00 | 0.6 |
| 15:35:00 | 0.624 | 15:35:00 | 0.516 | 15:35:00 | 0.588 |
| 15:40:00 | 0.612 | 15:40:00 | 0.516 | 15:40:00 | 0.588 |
| 15:45:00 | 0.612 | 15:45:00 | 0.504 | 15:45:00 | 0.6 |
| 15:50:00 | 0.615 | 15:50:00 | 0.516 | 15:50:00 | 0.588 |
| 15:55:00 | 0.624 | 15:55:00 | 0.516 | 15:55:00 | 0.6 |
| 16:00:00 | 0.612 | 16:00:00 | 0.492 | 16:00:00 | 0.6 |
| 16:05:00 | 0.6 | 16:05:00 | 0.504 | 16:05:00 | 0.6 |
| 16:10:00 | 0.612 | 16:10:00 | 0.48 | 16:10:00 | 0.588 |
| 16:15:00 | 0.612 | 16:15:00 | 0.492 | 16:15:00 | 0.588 |
| 16:20:00 | 0.612 | 16:20:00 | 0.492 | 16:20:00 | 0.588 |
| 16:25:00 | 0.6 | 16:25:00 | 0.492 | 16:25:00 | 0.6 |
| 16:30:00 | 0.6 | 16:30:00 | 0.516 | 16:30:00 | 0.588 |
| 16:35:00 | 0.6 | 16:35:00 | 0.492 | 16:35:00 | 0.588 |
| 16:40:00 | 0.6 | 16:40:00 | 0.468 | 16:40:00 | 0.588 |
| 16:45:00 | 0.6 | 16:45:00 | 0.48 | 16:45:00 | 0.588 |
| 16:50:00 | 0.6 | 16:50:00 | 0.468 | 16:50:00 | 0.588 |
| 16:55:00 | 0.588 | 16:55:00 | 0.48 | 16:55:00 | 0.576 |
| 17:00:00 | 0.588 | 17:00:00 | 0.48 | 17:00:00 | 0.576 |
| 17:05:00 | 0.588 | 17:05:00 | 0.48 | 17:05:00 | 0.576 |
| 17:10:00 | 0.588 | 17:10:00 | 0.48 | 17:10:00 | 0.576 |
| 17:15:00 | 0.588 | 17:15:00 | 0.48 | 17:15:00 | 0.576 |
| 17:20:00 | 0.576 | 17:20:00 | 0.48 | 17:20:00 | 0.564 |
| 17:25:00 | 0.576 | 17:25:00 | 0.492 | 17:25:00 | 0.564 |
| 17:30:00 | 0.588 | 17:30:00 | 0.48 | 17:30:00 | 0.564 |
| 17:35:00 | 0.564 | 17:35:00 | 0.48 | 17:35:00 | 0.564 |
| 17:40:00 | 0.576 | 17:40:00 | 0.504 | 17:40:00 | 0.552 |
| 17:45:00 | 0.5 | 17:45:00 | 0.504 | 17:45:00 | 0.552 |
| 17:50:00 | 0.45 | 17:50:00 | 0.48 | 17:50:00 | 0.552 |
| 17:55:00 | 0.348 | 17:55:00 | 0.504 | 17:55:00 | 0.552 |

| | | | | | |
|---|---|---|---|---|---|
| 18:00:00 | 0.336 | 18:00:00 | 0.312 | 18:00:00 | 0.54 |
| 18:05:00 | 0.432 | 18:05:00 | 0.276 | 18:05:00 | 0.54 |
| 18:10:00 | 0.348 | 18:10:00 | 0.36 | 18:10:00 | 0.54 |
| 18:15:00 | 0.324 | 18:15:00 | 0.396 | 18:15:00 | 0.54 |
| 18:20:00 | 0.288 | 18:20:00 | 0.456 | 18:20:00 | 0.54 |
| 18:25:00 | 0.348 | 18:25:00 | 0.36 | 18:25:00 | 0.54 |
| 18:30:00 | 0.432 | 18:30:00 | 0.312 | 18:30:00 | 0.528 |
| 18:35:00 | 0.348 | 18:35:00 | 0.252 | 18:35:00 | 0.456 |
| 18:40:00 | 0.336 | 18:40:00 | 0.216 | 18:40:00 | 0.36 |
| 18:45:00 | 0.264 | 18:45:00 | 0.192 | 18:45:00 | 0.288 |
| 18:50:00 | 0.3 | 18:50:00 | 0.204 | 18:50:00 | 0.24 |
| 18:55:00 | 0.264 | 18:55:00 | 0.192 | 18:55:00 | 0.204 |
| 19:00:00 | 0.168 | 19:00:00 | 0.192 | 19:00:00 | 0.18 |
| 19:05:00 | 0.108 | 19:05:00 | 0.12 | 19:05:00 | 0.156 |
| 19:10:00 | 0.072 | 19:10:00 | 0.06 | 19:10:00 | 0.12 |
| 19:15:00 | 0.036 | 19:15:00 | 0.024 | 19:15:00 | 0.096 |
| 19:20:00 | 0.012 | 19:20:00 | 0 | 19:20:00 | 0.072 |
| 19:25:00 | 0.012 | 19:25:00 | 0 | 19:25:00 | 0.36 |
| 19:30:00 | 0 | 19:30:00 | 0 | 19:30:00 | 0.012 |
| 19:35:00 | 0 | 19:35:00 | 0 | 19:35:00 | 0 |
| 19:40:00 | 0 | 19:40:00 | 0 | 19:40:00 | 0 |
| 19:45:00 | 0 | 19:45:00 | 0 | 19:45:00 | 0 |
| 19:50:00 | 0 | 19:50:00 | 0 | 19:50:00 | 0 |
| 19:55:00 | 0 | 19:55:00 | 0 | 19:55:00 | 0 |
| 20:00:00 | 0 | 20:00:00 | 0 | 20:00:00 | 0 |
| 20:05:00 | 0 | 20:05:00 | 0 | 20:05:00 | 0 |
| 20:10:00 | 0 | 20:10:00 | 0 | 20:10:00 | 0 |
| 20:15:00 | 0 | 20:15:00 | 0 | 20:15:00 | 0 |
| 20:20:00 | 0 | 20:20:00 | 0 | 20:20:00 | 0 |
| 20:25:00 | 0 | 20:25:00 | 0 | 20:25:00 | 0 |
| 20:30:00 | 0 | 20:30:00 | 0 | 20:30:00 | 0 |
| 20:35:00 | 0 | 20:35:00 | 0 | 20:35:00 | 0 |
| 20:40:00 | 0 | 20:40:00 | 0 | 20:40:00 | 0 |
| 20:45:00 | 0 | 20:45:00 | 0 | 20:45:00 | 0 |
| 20:50:00 | 0 | 20:50:00 | 0 | 20:50:00 | 0 |
| 20:55:00 | 0 | 20:55:00 | 0 | 20:55:00 | 0 |
| 21:00:00 | 0 | 21:00:00 | 0 | 21:00:00 | 0 |
| 21:05:00 | 0 | 21:05:00 | 0 | 21:05:00 | 0 |
| 21:10:00 | 0 | 21:10:00 | 0 | 21:10:00 | 0 |
| 21:15:00 | 0 | 21:15:00 | 0 | 21:15:00 | 0 |
| 21:20:00 | 0 | 21:20:00 | 0 | 21:20:00 | 0 |

| | |
|---|---|
| 21:25:00 | 0 |
| 21:30:00 | 0 |
| 21:35:00 | 0 |
| 21:40:00 | 0 |
| 21:45:00 | 0 |
| 21:50:00 | 0 |
| 21:55:00 | 0 |
| 22:00:00 | 0 |
| 22:05:00 | 0 |
| 22:10:00 | 0 |
| 22:15:00 | 0 |
| 22:20:00 | 0 |
| 22:25:00 | 0 |
| 22:30:00 | 0 |
| 22:35:00 | 0 |
| 22:40:00 | 0 |
| 22:45:00 | 0 |
| 22:50:00 | 0 |
| 22:55:00 | 0 |
| 23:00:00 | 0 |
| 23:05:00 | 0 |
| 23:10:00 | 0 |
| 23:15:00 | 0 |
| 23:20:00 | 0 |
| 23:25:00 | 0 |
| 23:30:00 | 0 |
| 23:35:00 | 0 |
| 23:40:00 | 0 |
| 23:45:00 | 0 |
| 23:50:00 | 0 |
| 23:55:00 | 0 |

| | |
|---|---|
| 21:25:00 | 0 |
| 21:30:00 | 0 |
| 21:35:00 | 0 |
| 21:40:00 | 0 |
| 21:45:00 | 0 |
| 21:50:00 | 0 |
| 21:55:00 | 0 |
| 22:00:00 | 0 |
| 22:05:00 | 0 |
| 22:10:00 | 0 |
| 22:15:00 | 0 |
| 22:20:00 | 0 |
| 22:25:00 | 0 |
| 22:30:00 | 0 |
| 22:35:00 | 0 |
| 22:40:00 | 0 |
| 22:45:00 | 0 |
| 22:50:00 | 0 |
| 22:55:00 | 0 |
| 23:00:00 | 0 |
| 23:05:00 | 0 |
| 23:10:00 | 0 |
| 23:15:00 | 0 |
| 23:20:00 | 0 |
| 23:25:00 | 0 |
| 23:30:00 | 0 |
| 23:35:00 | 0 |
| 23:40:00 | 0 |
| 23:45:00 | 0 |
| 23:50:00 | 0 |
| 23:55:00 | 0 |

| | |
|---|---|
| 21:25:00 | 0 |
| 21:30:00 | 0 |
| 21:35:00 | 0 |
| 21:40:00 | 0 |
| 21:45:00 | 0 |
| 21:50:00 | 0 |
| 21:55:00 | 0 |
| 22:00:00 | 0 |
| 22:05:00 | 0 |
| 22:10:00 | 0 |
| 22:15:00 | 0 |
| 22:20:00 | 0 |
| 22:25:00 | 0 |
| 22:30:00 | 0 |
| 22:35:00 | 0 |
| 22:40:00 | 0 |
| 22:45:00 | 0 |
| 22:50:00 | 0 |
| 22:55:00 | 0 |
| 23:00:00 | 0 |
| 23:05:00 | 0 |
| 23:10:00 | 0 |
| 23:15:00 | 0 |
| 23:20:00 | 0 |
| 23:25:00 | 0 |
| 23:30:00 | 0 |
| 23:35:00 | 0 |
| 23:40:00 | 0 |
| 23:45:00 | 0 |
| 23:50:00 | 0 |
| 23:55:00 | 0 |